preapplication treatment. Wastewater constituents that may tend to limit the application rate or hinder the quality of renovated water may also necessitate pretreatment. High concentrations of grit, suspended solids and grease and oil can deteriorate the effectiveness and dependability of the pumping and distribution systems, thus requiring some degree of pretreatment prior to application.

Storage Requirements - In most land application systems, considerations in determining storage capacity include the local climate, the design period of operation, flow equalization, and system back-up if breakdown occurs. Required storage capacities may range from one day's storage to several months'.

Storage requirements will most often be based on the period of operation and the local climate. Three different conditions that may necessitate storage include: 1) winter weather requiring cessation of operation; 2) precipitation requiring the temporary reduction or cessation of application; or 3) winter weather requiring reduction of winter application rates. When cessation of operation is expected, storage requirements should be based on the maximum expected period of nonoperation. The number of consecutive nonapplication days due to climatic constraints (i.e. precipitation, temperature and snow) may be determined through the use of a computer program developed by the National Weather Service (54). Figure 11 presents a nationwide estimation of storage days as calculated from this computer program.

Climatic Factors - Design assumptions must be evaluated with regard to climatic factors. Climatic conditions most often considered are precipitation, temperature and wind.

Precipitation, such as rainfall, snow and hail, will affect a number of design factors, such as: 1) hydraulic loading rates; 2) storage requirements, and 3) system drainage requirements. Precipitation data that will be necessary for design purposes include: total annual precipitation; maximum and minimum annual precipitation; monthly distribution of precipitation; storm intensities; and snowfall characteristics.

Temperature, because of its influence on plant growth and freezing conditions, will affect liquid loading rates and the period of operation. Temperature data that may be incorporated into system design include: monthly or seasonal averages and variations; length of growing season; and periods of freezing conditions.

For spray application systems, wind conditions may require a reduction or temporary cessation of waste application in order to prevent disease transmission. Wind velocity and direction should be determined with respect to frequencies and durations.

Another climatological factor that should be considered is the potential amount of evapotranspiration for the area. Figure 12 presents a nationwide comparison of potential evapotranspiration rates versus the mean annual precipitation. The effect of the evapotranspiration, if the yearly evapotranspiration, is greater than the mean annual precipitation, is that it will reduce the liquid volume of waste to the applied on the land.

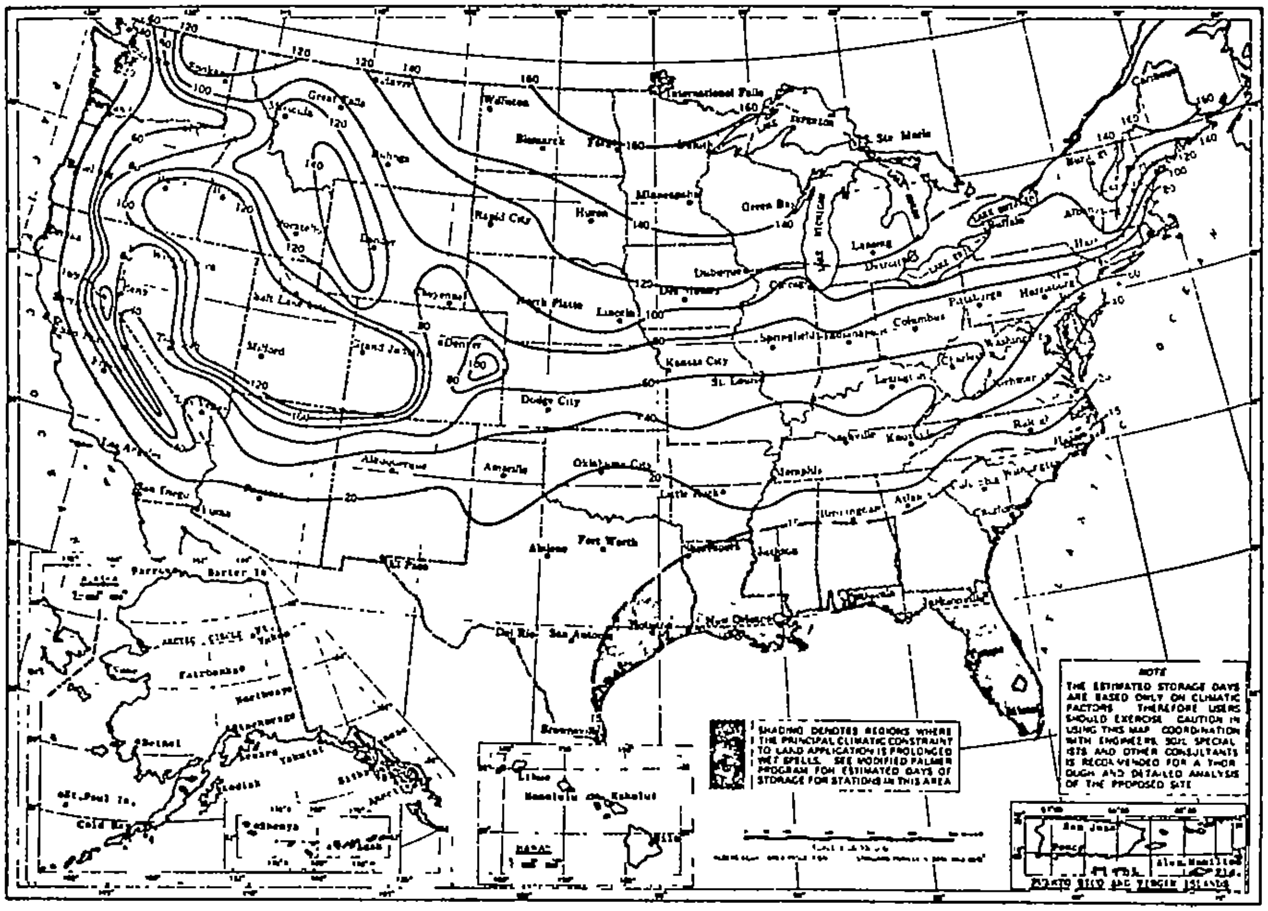

Figure 11. Storage days required as estimated from the use of the computer program as described (54).

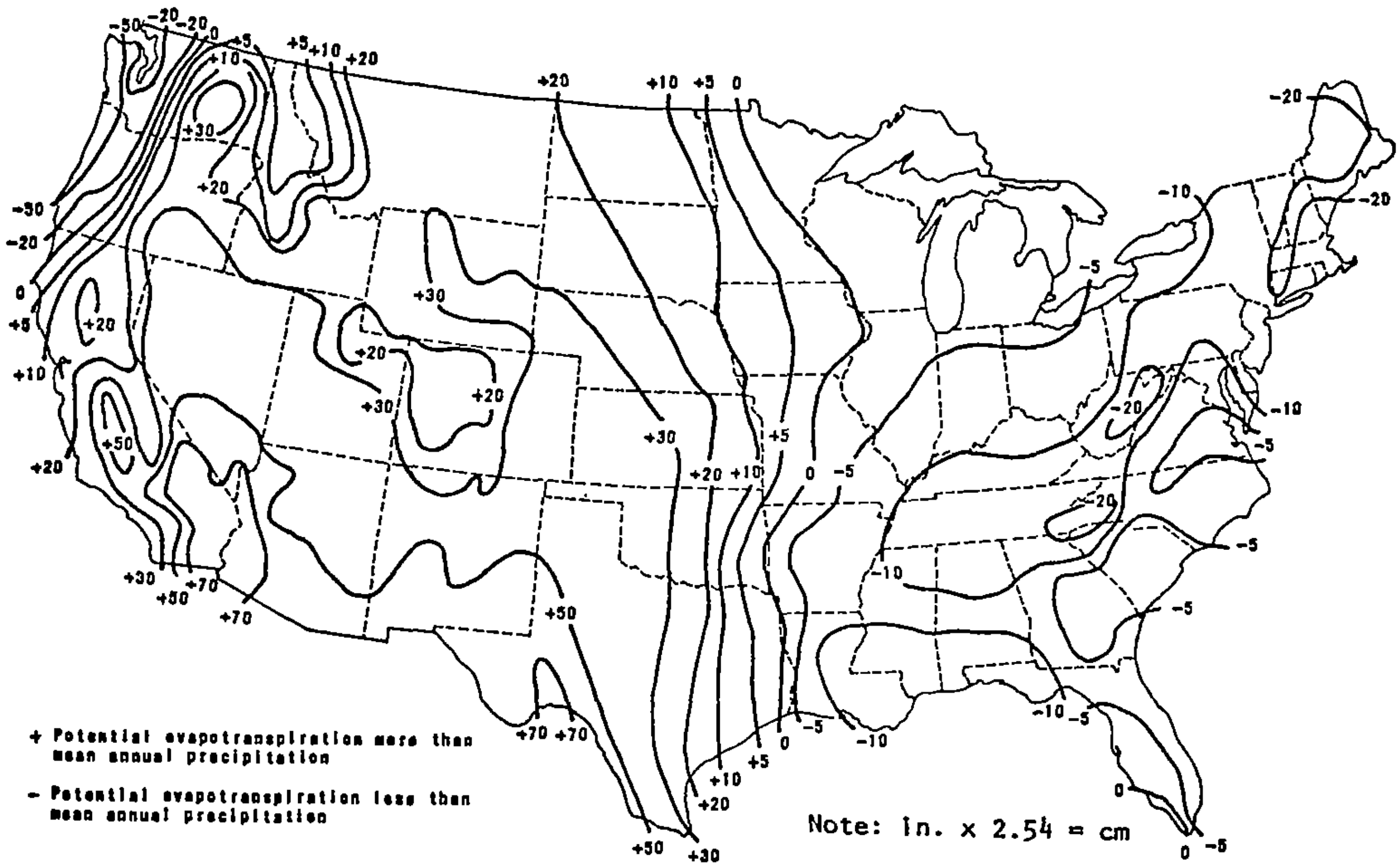

Figure 12. Potential evapotranspiration vs. mean annual precipitation (inches) (46).

Pollutional Loading Constraints - Loading rates for the liquid applied and the pollutional constituents of the waste will form the basis in determining design criteria for land requirements, application rates, and crop selection. To determine what characteristics of the applied waste will be limiting, balances should be conducted for water, nitrogen, phosphorus, organic matter, and other constituents that appear high in concentration. On the basis of these balances, a loading rate can be established for each parameter which then can be used in calculating the required land area. The critical loading rate will be the one requiring the largest field area.

The hydraulic loading rate can be determined by conducting a water balance on the effluent applied, precipitation, evapotranspiration, percolation, and runoff. In other words, the amount of effluent applied plus precipitation should equal the evapotranspiration plus a limited amount of percolation. In all cases except overland flow, surface runoff from irrigated fields should not be permitted. The water balance can be expressed as:

$$\text{Precipitation} + \begin{matrix}\text{Applied}\\ \text{Effluent}\end{matrix} = \text{Evapotranspiration} + \text{Percolation } [+ \text{ Runoff}]$$

Seasonal variations should be taken into account when encountering these values. This can be done by means of evaluating the water balance for each month as well as the annual balance.

Nitrogen loadings must be balanced against acceptable nitrogen losses and removals because nitrate ions are mobile in the soil and can affect groundwater quality. On an annual basis, the applied nitrogen must be accounted for in crop uptake, denitrification, volatilization, leachate, or storage in the soil. A nitrogen mass balance equation for a terrestrial system can be developed as:

$$\begin{matrix}\text{Applied}\\ \text{N in}\\ \text{waste}\end{matrix} + \begin{matrix}\text{N in}\\ \text{precipi-}\\ \text{tation}\end{matrix} = \begin{matrix}\text{N Removal}\\ \text{in crops}\end{matrix} + \begin{matrix}\text{Leaching}\\ \text{Loss}\end{matrix} + \begin{matrix}\text{Denitri-}\\ \text{fication}\end{matrix} + \begin{matrix}NH_3\\ \text{Volatili-}\\ \text{zation}\end{matrix}$$

This balance equation can be used to calculate nitrogen loading rates for waste applications.

For most land application systems, the phosphorus loading will usually be well below the capacity of the soil to fix and precipitate the phosphorus. Typically, 95 percent of the phosphorus applied can be removed from the percolating wastewater. The removal mechanisms for phosphorus are crop uptake, microbial uptake, chemical precipitation, and fixation by the soil.

The average daily organic loading rate should be calculated from the hydraulic loading rate and the BOD concentration of the applied waste. Thomas (55) has estimated that organic loading rates between 11 to 28 kg/ha/day (10 to 25 lb/acre/day) are needed to maintain a static organic-matter content in the soil. Additions of organic matter at these rates help to maintain the tilth of the soil, replenish the carbon oxidized by microorganisms, and would not be expected to pose problems of soil clogging. Higher loadings rates of 56 to 112 kg/ha/day (50 to 100 lb/acre/day) can be employed successfully, depending upon the type of system and the resting period. Resting periods, which are standard with most application systems, give soil bacteria time to break down organic matter and allow the water to drain from the top few inches, thus restoring aerobic conditions.

Loading rates for suspended and dissolved solids are the two major types of remaining constituents that are of interest for land application systems. The organic and inorganic fractions of the suspended solids are usually filtered out and become incorporated into the soil, which can reduce the infiltration rate into the soil. As a result, preapplication treatment for suspended solids reduction may be necessary.

Dissolved solids are affected differently in the soils depending on their movement through the soil matrix. Chlorides, sulfates, nitrates, and bicarbonates move relatively easy through most soils without being tied up in the soil profile. These compounds can, therefore, be readily leached into the groundwater. Other dissolved solids, such as sodium, potassium, calcium, and magnesium, are exchangeable and react with the soil so that their concentrations will change with depth. Other constituents, such as heavy metals, pesticides and other trace elements may or may not be removed by the soil matrix, depending upon such factors as clay content, soil pH and soil chemical balance. On the basis of the analyses of waste characteristics, any constituent suspected of having a limiting loading rate should be calculated. Table 37 gives recommended concentration limits for specific elements based on common application rates for land application systems. If the limiting criteria is met, there should be little concern about toxic effects on plants or excessive accumulation in soils.

<u>Land Area Requirements</u> - The total land area required includes provisions for treatment; buffer zones; storage; sites for buildings, roads and ditches; and land for emergencies or future expansion. If any on-site preapplication treatment is required, provisions must also be provided for land furnishing these facilities.

The field area is that portion of the disposal site in which the waste is applied to the land. It is determined by calculating acceptable loading rates for each different loading parameter (liquid, nitrogen, phosphorus, organic, or others) and then selecting the largest area. The loading parameter that corresponds to the largest field area requirement would then be the critical loading parameter.

Regulatory agency requirements may specify buffer zones around application sites because of concern about the effects of aerosol-borne pathogens. Buffer zones ranging from 15 to 61 meters (50 to 200 ft) wide have been reported (45), although requirements for even larger buffer zones may exist depending on a number of factors.

Land application systems will generally require land for off-season or

TABLE 37. RECOMMENDED AND ESTIMATED MAXIMUM CONCENTRATIONS OF SPECIFIC IONS IN IRRIGATION WATERS (1), mg/l (46)

		For Waters Used Continuously on All Soil	For Waters Used Up to 20 Years on Fine-Textured Soils of pH 6.0 to 8.5		
Element	Removal Mechanism (2)	0.9 m/yr Application Recommended Limit (3)	0.9 m/yr Application Recommended Limit (3)	2.4 m/yr Application Estimated Limit	24 m/yr Application Estimated Limit
Aluminum	PR, S	5.0	20.0	8.0	0.8
Arsenic	AD, S	0.10	2.0	0.8	0.08
Beryllium	PR	0.10	0.50	0.2	0.02
Boron	AD, W	0.75	2.0-10.0	2.0	2.0
Cadmium	AD, CE, S	0.010	0.050	0.02	0.002
Chromium	AD, CE, S	0.10	1.0	0.4	0.04
Cobalt	AD, CE, S	0.050	5.0	2.0	0.2
Copper	AD, CE, S	0.20	5.0	2.0	0.2
Fluoride	AD, S	1.0	15.0	6.0	0.6
Iron	PR, CE, S	5.0	20.0	8.0	0.8
Lead	AD, CE, S	5.0	10.0	4.0	0.4
Lithium	CE, W	2.5 (4)	2.5 (4)	2.5	2.5
Manganese	PR, CE, S	0.20	10.0	4.0	0.4
Mercury	AD, CE, S	---	---	---	---
Molybdenum	AD, S	0.010	0.050 (5)	0.02 (5)	0.002 (5)
Nickel	AD, CE, S	0.20	2.0	0.8	0.08
Selenium	AE, W	0.020	0.020	0.02	0.02
Silver	AD, CE, S	---	---	---	---
Zinc	AD, CE, S	2.0	10.0	4.0	0.4

(1) These levels will normally not adversely affect plants or soils. No data are available for mercury, silver, tin, titanium, or tungsten.

(2) AD = adsorption with iron or aluminum hydroxide, pH dependent; AD = anion exchange; CE = cation exchange; PR = precipitate, pH dependent--iron and manganese are also subject to changes by oxidation reduction reaction; S = strong strength of removal; W = weak strength of removal

(3) EPA Water Quality Criteria, 1972.

(4) Recommended maximum concentration for irrigating citrus is 0.075 mg/l.

(5) For only acid fine-textured soils or acid soils with relatively high iron oxide contents.

winter storage, especially in the northern states. Storage capacities may also be necessary to equalize flow rates or to provide backup services.

Crop Selection and Management - Crops grown at the land application site can have a significant effect on treatment efficiencies and loading rates, especially the removal of nutrients from the applied waste. Factors that should be considered in crop selection include: 1) relationship to critical loading, 2) public health regulations, 3) ease of cultivation and harvesting, and 4) the length of the growing season. Also, if the crop is to be harvested, the local market for the crop must be considered. The four general classes of crops that may be considered are perennials, annuals, landscape vegetation, and forest vegetation.

Compatibility of the loading rates with the selected crop is important to ensure both the survival of the crop and the efficiency of wastewater renovation. Loading rates should have allowances with respect to the tolerances and uptake capacities of the intended crops. Therefore, crop selection will be dependent on a combination of loading parameters, including 1) water requirement and tolerance, 2) nutrient requirement, tolerance, and removal capability, and 3) sensitivity to various inorganic ions.

As of 1972, at least 17 states had public health regulations that exist with regard to: the types of crops that may be irrigated with wastewater; the degree of preapplication treatment required for certain types of crops; and the methods of application that may be employed (56).

System Components - Typically, land application systems are composed of a number of different system components, such as: preapplication treatment facilities, transmission facilities, storage facilities, distribution system, recovery system and monitoring system. The design of each component of a land application system is highly variable and is dependent on many factors relating to site characteristics and project objectives.

The design of preapplication treatment facilities will be controlled by factors such as the loading rate of various constituents, the method of application employed, and the type of crop grown. In most cases, regulations concerning required levels of preapplication treatment have been set forth by local agencies.

Design of the transmission facilities to the site from the collection area may become a very important aspect to consider if land application is to be cost-effective. Selection of a conveyance method will usually depend on the production rate, distance to application site, seasonability of application, and planned lifetime of the site. Three potential methods of wastewater conveyance include gravity piping, open channels and force mains. For each of these methods, standard design criteria should be used since these transmission facilities will rarely differ from that designed for conventional treatment systems. In conveying sludges, additional methods have included tank trucking for liquid sludges and open bed trucking for dewatered sludges.

In almost all cases, some sort of storage facility will be necessary. If storage is to be provided for winter flows and storage requirements are high, winter storage, especially in the northern states. Storage capacities may also be necessary to equalize flow rates or to provide backup services.

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TABLE 38. IMPORTANT MONITORING SEGMENTS OF LAND APPLICATION PROCESS (59)

I. Influent Quality (Treatment Quality)

   a. Nutrient levels (N, P, K)
   b. Sodium absorption ratio (SAR)
   c. Heavy metal concentration, having potential toxicity to plant and animal life (Zn, Cu, Ni, Cd, Pb, Hg)
   d. Other physical and chemical determinations (pH, BOD, COD, TS, TOC)
   e. Pathogens, viruses, salmonella and protozoa

II. Soil Condition and Quality (Preservation of Soil's Physical & Chemical Characteristics)

   a. Nutrient profile - N, P, K distribution
   b. Cation exchange capacity
   c. Hazardous heavy metal distribution
   d. Organic content
   e. Soil kind - physical
      - infiltration rate
      - size distribution
      - soil horizons
      - redox profile, pH

III. Drained or Leachate Water Quality and Groundwater (Prevention of Contamination of Surface and Groundwater)

   1. Groundwater
      a. Nutrients (NO_3/NO_2, P)
      b. Heavy metals
      c. Pesticides, herbicides, etc.
      d. Microbiological
         - fecal coliform
         - fecal strep
         - salmonella
         - viruses
      e. Other physical, chemical determinations
         - pH, specific conductivity, detergents

   2. Receiving Surface Waters
      a. Nutrients
      b. Heavy metals
      c. Microbiological
         - fecal coliform
      d. Other physical and chemical determinations

   3. Crop Quality and Yield (Safe for Animal/Human Consumption)
      a. Heavy metals content
      b. Nutrient content
      c. Pathogens

---

gradient groundwater quality, as well as influent to the system, should be monitored for the parameters commonly measured to ensure environmental quality and any additional parameters that are of concern to the land application system, such as heavy metals. In the case of overland flow application, the effluent discharging from the site will have to be monitored for the parameters required by state and federal discharge requirements.

In addition to quality, changes in groundwater levels should also be monitored. The effect of increased levels should be assessed with respect to changes in the hydrogeologic conditions of the area. Changes in the groundwater movement and the appearance of seeps and perched water tables should be noted and system modifications, such as underdraining or reducing application rates in the area should be undertaken (46).

When vegetation is grown as a part of the treatment system, monitoring may be required for the purpose of optimizing growth and yield and preventing buildup of toxic materials. Measurements should include: heavy metal content; nutrient content; and pathogens.

Cost-Effectiveness - In selecting the best wastewater treatment alternative, a cost-effectiveness analysis should be properly performed. To conduct such an analysis, detailed cost estimates must be prepared and evaluated for each alternative on an equivalent basis in terms of total present worth or annual cost. Generally, cost estimates for an alternative would include costs for operation, maintenance and supervision and the amortized capital cost. Capital and operating cost considerations of importance for land application systems have been documented in current reports entitled "Costs of Wastewater Treatment by Land Application" (48) and "Water Pollution Abatement Technology: Capabilities and Cost" (43).

LAND APPLICATION OF RAW CSO

An alternative to the treatment of CSO and the resultant problems of sludge handling and disposal is direct application of the raw CSO to the land. This method would eliminate the need for extensive CSO treatment facilities and the further problem of sludge handling and disposal facilities.

The waste management alternative of applying raw CSO to the land will be discussed with respect to many of the design factors presented in the previous section.

Preapplication Treatment

If the land is used for treatment and disposal of raw CSO, it is apparent that some form of preapplication treatment will be required. First, since high densities of coliform have been reported for CSO (9), disinfection will most likely be required as a preapplication treatment process. Second, since CSO's are intermittent events, storage will have to be provided to equalize the flow to the land site and thus, some type of stabilization to prevent nuisance conditions from developing will be required. If spray irrigation is employed, grit, oil and grease removal combined with a reduction in suspended solids may be necessary to prevent potential clogging of the distribution system. Since the raw flow will be held in a storage facility, grit and organic solids could be removed there and some provision would have to be made for disinfection prior to land application.

Collection and Transportation of Raw CSO

A very important aspect to consider, if land disposal of raw CSO is to be used, is how the CSO will be collected and transported to the land disposal site. The cost of such a collection and transportation system could be more than the land disposal facility itself. In most cities, a collection system will be necessary to intercept all CSO discharge points and deliver the flows to a transport system. The collection system must function year round and must be sized to carry peak flows. The transport system would have to convey the CSO out of the urban and suburban areas to a selected land site. The transport system normally would be a pipeline but under some circumstances, could be an open channel.

Several problems will become apparent when implementing conceptural plans for transmission facilities. First, combined sewers are usually located in the older, central sections of metropolitan areas. Therefore, the collection system may require sewer construction in densely populated commercial areas, which could prove to be very costly. Second, in order to convey the CSO out of the urban area to a selected treatment site, the transportation distance could easily be 32 to 64 km (20 to 40 miles). These distances may prove to be impractical because of the high costs for transportation systems. Third, and probably most important, the transmission facilities must be capable of handling peak storm flows. To illustrate this better, a typical city in the Great Lakes region with a combined sewer area of 972 ha (2400 acres), would require transport pipelines in the order of 5.3 m (17.5 ft) in diameter to provide for peak flow design rates based on one hour storm intensities at one year return frequencies. If longer return periods or shorter time intervals are used in order to achieve complete CSO abatement, the sizes of the collection and transport systems would increase significantly. To avoid the design capacities needed for peak flow rates, it would be necessary to provide for equalization basins and temporary storage basins to maintain a constant transportation program. The cost for these facilities alone may be prohibitive.

Storage

Design considerations for storage facilities are usually based upon incoming flow rates and the number of consecutive unfavorable application days over the year. The nonapplication period is determined by the number of days during which the following exist: temperature below freezing $0^{\circ}C$ ($32^{\circ}F$), total daily rainfall greater than 1.3 cm (0.5 inches), and greater than 2.5 cm (1 inch) of snow cover (54). For the Great Lakes and Northeastern regions of the U.S., the average number of nonapplication days for which storage would normally be required is around 100 days (Figure 10). However, in determining the storage requirement, it is necessary to conduct a monthly water balance considering intermittent CSO flow rates, precipitation, evaporation and soil percolation rates.

Therefore, it appears that storage facilities will be required to handle CSO flows for periods up to four months. In addition to providing storage facilities, because of the large amounts of solids that can be expected in raw CSO, precautions will have to be taken to prevent nuisance problems from occurring. These precautions could be stabilization and/or disinfection of the CSO during storage and a mosquito control program. The storage area could also support extensive algal growths which could become a significant problem.

Climatological Effects

The general climate of the area can have a significant effect on the operation of a CSO land disposal site. As seen from the previous discussion, the winter season will greatly reduce the time that a land disposal operation can be used. On the average, the operation of a site in the Great Lakes region would have to be shut down for 3 1/2 months.

The yearly precipitation over the area will also affect the operation since the irrigation or overland flow methods of application can not be used during periods of rainfall because the highly polluted CSO could be carried away from the site with the surface runoff. Wet ground that results from the rainfall events will also reduce the capacity of the soil to hydraulically assimilate the added loadings of the raw CSO. These factors will increase the amount of land required for the disposal site. The days of operation were approximated as 205 days for an average year in the Great Lakes region of the country. This value was arrived at by subtracting 100 days for winter conditions and 60 days for non-operative conditions due to periods of rainfall-runoff.

Another climatological factor that should be considered is the potential amount of evapotranspiration for the area. The effect of the evapotranspiration rates can be shown by using the Great Lakes region of the country as an example. From Figure 11, it is estimated that the potential yearly evapotranspiration is less than the mean annual precipitation rate. The impact of evapotranspiration is that it must be considered as part of the hydraulic loading. Therefore, it will not significantly reduce the added precipitation that will necessitate disposal.

It can be seen that for the Great Lakes and the Northeastern regions of the USA, the precipitation and evapotranspiration rates can be significant factors affecting the liquid volume of the waste to be handled.

Pollutant Loading Constraints

Since CSO represents large quantities of urban runoff, it can contain large concentrations of heavy metals which may be in excess of those that can be removed by the soil. The leaching of these metals into the receiving water could pose a serious health problem. This fact, and the fact that high concentrations of some pollutants in CSO may cause operational problems for the land disposal site, may lead to constraints on the loading rates allowed and thus, on the overall feasibility of land disposal of raw CSO. As the first consideration in design, the factors which may limit land disposal of wastes and the risks involved with this practice will be estimated. This will be accomplished by identifying the parameter that limits loading rates.

For preliminary calculation purposes, the following CSO values, based on average characteristics obtained from the literature, have been assigned for use in this section. The raw CSO volume is an arbitrary value to serve as a basis for design calculations.

Raw CSO volume: 1382×10^6 ℓ/yr (365×10^6 gal./yr)
Yearly CSO solids volume: 552 metric tons (609 tons-dry weight basis)

Pollutional Characteristics:

SS	400 mg/l	
BOD	120 mg/l	
N	16 mg/l	
P	5 mg/l	
Zn	1000 mg/kg	SS
Cu	400 mg/kg	SS
Ni	200 mg/kg	SS

Toxic Elements - The most common concern with land application of pollutants is the question of the effect of toxic elements on the soil-crop system. In order to protect the land from toxic elements accumulation from waste applications, Wisconsin (60) has adopted guidelines, based on an interim guide recommended by the EPA, which takes into account the combined effect of the metals by using a measurement entitled the zinc equivalent (ZE). The ZE can be determiend as follows:

$$ZE = (1 \times [Zn]) + (2 \times [Cu]) + (4 \times [Ni])$$

where all concentration values are expressed in mg/kg dry weight. The total dry solids loading is calculated from the formula (60):

$$\text{Total Solids } \left(\frac{\text{dry tons}}{\text{acre}}\right) = \frac{32{,}500 \times CEC}{ZE}$$

To determine area requirements, the following assumptions were made: 1) the cation exchange capacity (CEC) of the soil is 15 meq/100 g; and 2) the life span for the soil is 20 years. As a result, the area requirements for land application of CSO would be about 1.9×10^{-2} ha/10^6 ℓ CSO/yr (17.8×10^{-2} ac/10^6 gal. CSO/yr).

Organic Solids Application Rates - The organic assimilation capacity of soils is highly variable depending on detailed soil characteristics. In general, organics are continuously added to soils as plant residues, dead animals, etc. and are continuously oxidized by soil organisms. As organic additions increase, soil respiration also increases until a maximum rate of oxidation is reached. Although few guides are available, regulations have been proposed to limit BOD_5 and SS application rates to around 672.6 kg/ha-day (600 lbs/acre-day). If this limitation is used, the safe application areas for raw CSO wastes would be 0.4×10^{-2} ha/10^6 ℓ CSO/yr (3.7×10^{-2} ac/10^6 gal. CSO/yr) for BOD and 1.6×10^{-2} ha/10^6 ℓ CSO/yr (15.0×10^{-2} ac/10^6 gal. CSO/yr) for SS.

Nitrogen and Phosphorus Control - The nitrogen and phosphorus constituents in CSO wastewater are likely to appear as major limiting factors for land application designs. Current knowledge indicates that phosphorus removal to levels of 0.05 mg/l can be achieved over site lifetimes of 20 years or more at annual loading rates within the 168 to 336 kg P/ha-yr (150-300 lb P/acre - yr) range (6). Using this assumption, the total land area required for safe application of phosphorus would be 1.9×10^{-2} ha/10^6 ℓ CSO/yr (17.8×10^{-2} ac/10^6 gal. CSO/yr).

Conversion of nitrogen forms to nitrates may result in contamination of the groundwater. Thus, nitrogen must be considered as a nutrient which must be applied at a controlled rate. To calculate nitrogen loading rates for wastewater applications, the following equation can be used (6):

$$N^* = \frac{y}{4.43} \left(\frac{4.43\ C + a(P-ET) - cP}{y-a}\right)$$

where:

N = total nitrogen in applied waste (lb/ac-yr)
C = removal of N in crop (lb/ac-yr)
P = precipitation (ac-in./ac-yr)
c = concentration of N in precipitation (mg/l)
a = allowable N in leachate (mg/l)
ET = potential evapotranspiration (ac-in./ac-yr)
y = total nitrogen concentration in waste (mg/l)

* conversion factor = N x 1.122 = kg N/ha-yr

The following assumptions are made to determine nitrogen loading rates for an area in the Great Lakes region: 1) average annual precipitation is 89 ha-cm/ha-yr (35 ac-in./ac-yr); 2) evapotranspiration is 51 ha-cm/ha-yr (20 ac-in./ac-yr); 3) allowable N concentration in leachate is 10 mg/l; and 4) crop nitrogen removal rate is 280 kg/ha-yr (250 lb/ac-yr).

Using these assumptions, the wastewater application rate would be approximately 834 kg N/ha-yr (743 lb N/ac-yr), thus resulting in a land area requirement of 1.9×10^{-2} ha/10^6 ℓ CSO/yr (17.8×10^{-2} ac/10^6 gal. CSO/yr).

Hydraulic Loading - The maximum hydraulic loading rate for the CSO must also be taken into consideration. This rate will be dependent on the application method employed and the type of soil characteristics given for the area. First, it will be assumed that a loam type soil is characteristic of a possible land disposal site in the northern states. This soil type suggests the use of the irrigation method of land application. Secondly, it is assumed that an allowable liquid loading rate for the selected application method and the predominant soil type would be 12.7 cm per wk (5 in./wk). Finally, if the operational period is assumed as 30 weeks a year, the annual application rate becomes 381 cm (150 in.). This results in a land area requirement of 2.6×10^{-2} ha/10^6 ℓ CSO/yr (24.7×10^{-2} ac/ 10^6 gal. CSO/yr).

Land Area Requirements

After a suitable land site has been selected, the next consideration for a city using land disposal of raw CSO will be the amount of land required for actual application. For field area requirements, a summary of the application rates estimated to be acceptable and the resulting land requirements are shown in Table 39. It is perhaps surprising to note that the limiting factor is the hydraulic loading of the CSO. Hydraulics often is the limiting factor for application of wastewaters, usually in cases where the application rate is controlled by surface runoff and groundwater protection. Hence, if the liquid loading is assumed to determine the required land area, it can be seen that the application rates of the other pollutants are one-third to two-thirds that which is considered to be an environmentally safe rate of application. Therefore, recommendation of the use of a 2.9×10^{-2} ha/10^6 ℓ CSO/yr (27.1×10^{-2} ac/10^6 gal. CSO/yr) land area requirement should incorporate a safety factor large enough to account for unpredictable events. The above land area requirement can also be expressed in terms of a design application rate: 34.4×10^6 ℓ/ha/yr (3.6×10^6 gal./ac/yr).

This "first cut" land estimate can increase significantly as more criteria are considered because additional land may be required for storage and possible pretreatment facilities, necessary non-application buffer zones, runoff control structures, etc.

For example, the inclusion of a 122m (400 ft) buffer zone around the site increases the required area significantly; if 61 m (200 ft) is acceptable with a line of trees and shrubs, the area requirement still is significant. Other buffer areas may also be required within the site around roads, streams, buildings, and storage areas. This, of course, would further increase the area required for the total operation.

Employing an application rate of 34.4×10^6 ℓ/ha/yr (3.6×10^6 gal./ac/yr) and if the nationwide annual volume of CSO totals 5.60×10^9 cu m (1.48×10^{12} gal.), field area requirements for raw CSO disposal would approximate 166,500 ha (411,110 acres) of land. However, this is land required for actual disposal only. Assuming that, on the average, the land required for actual disposal is 70 percent of a disposal site, the nationwide disposal of raw CSO would require a total land area of 237,857 ha (587,300 acres).

Crops

As discussed in the previous section, the crops grown at the land application site can have a significant effect on treatment efficiencies and loading rates, especially for the removal of nutrients from the CSO. Since

TABLE 39. SUMMARY OF RECOMMENDED APPLICATION RATES FOR VARIOUS RAW CSO POLLUTANTS AND THE RELATED LAND AREA REQUIREMENT

Pollutant	Acceptable application rate		Land area requirement	
	kg/ha/yr	(lbs/ac/yr)	10^{-2} ha/10^6 ℓ/yr	(10^{-2} ac/10^6 gal./yr)
Toxic metals	21.0	(9.4)[a]	1.9	(15.8)
Nitrogen	834	(744)	1.9	(15.8)
Phosphorus	252	(225)	1.9	(15.8)
BOD	672	(600)[b]	0.4	(4.1)
SS	672	(600)[b]	1.6	(13.3)

[a] expressed as metric tons/ha/yr (tons/ac/yr) - dry weight basis

[b] expressed as kg/ha/day (lb/ac/day)

removal of nitrogen is a primary objective, a perennial forage grass appears to be the best selection because it can remove nitrogen to low concentrations (62). Reed canary grass has been shown to be effective in removing nitrogen; however, other grasses may be just as good and may respond better under some circumstances.

Monitoring

Contamination of groundwater is a public health aspect that must be considered. The proposed EPA regulations on National Primary Drinking Water Standards (49) must be maintained for the groundwater. The land disposal of large volumes of CSO has the potential to significantly increase the nitrate and total dissolved solids of the groundwater. Therefore, these parameters should be monitored closely. Since CSO represents large quantities of surface runoff, it could contain high concentrations of heavy metals and pesticides; concentrations in excess of what can be removed by the soil. Any leaching of these pollutants could pose a serious health problem. Due to the lack of information on the passage of the large concentrations of pollutants expected in CSO through the soil, extensive monitoring programs would have to be established to guard against contamination of groundwater and nearby surface waters that may be used as water supplies.

Another public health consideration for the land disposal site is maintaining crop quality. When vegetation is grown as a part of the land disposal system, a detailed vegetation monitoring program may be required in which the uptake of certain elements must be analyzed. The analysis is usually required because of the potentially toxic constituents that may be present in CSO in abnormally high concentrations.

Summary

Hence, it can be concluded that land application of CSO wastewaters to the soil may be a viable treatment alternative. However, land application has two major limitations in allowing the process to become cost-effective. First, regulations require the CSO to be disinfected and in some cases stabilized before application. This might prove to be a very costly expenditure. Secondly and most importantly, the cost of the collection-transport and/or equalization system may be the crucial factor in disallowing land disposal of CSO as an alternative to other CSO treatment methods. It may be feasible to use land disposal of the raw CSO in cities which have relatively small CSO areas and have land available in close proximity to the city, but cities with large CSO areas, even if the land is available, may find that the cost of the collection-transport system might be prohibitive.

LAND APPLICATION OF CSO SLUDGES

If CSO treatment is employed by a city, the residual sludges that are produced will require some method of treatment and disposal. One alternative that can be considered is land disposal. It could be land disposal of the liquid sludge which can range from 0.7 to about 4.0 percent solids depending on the CSO treatment process employed; or it could be land disposal of the sludge after it has undergone thickening and/or dewatering. The disposal of liquid sludge on land is popular because it can meet two basic objectives: simplicity and cost-effectiveness. The objectives of land disposing a dewatered sludge are similar to those for a liquid sludge, although in the latter case solids-liquid separation must be achieved prior to disposal. In both cases, the sludge may be useful as a soil conditioner or as fertilizer for crop growth.

The sludges that are produced by CSO treatment can vary greatly from the sludges that are produced at conventional municipal wastewater treatment plants. Therefore, any criteria developed for land disposal of municipal dry-weather sludges may not be applicable for land disposal of CSO sludges.

As with the land disposal of the raw CSO, this section will attempt to present the design considerations necessary for the land disposal of sludges, either liquid or dewatered, and then relate these considerations to the unique characteristics of CSO produced sludges and to the problems that may be caused by these characteristics.

Preapplication Treatment

Variable characteristics, presented earlier in Tables 4, 5 and 6 have been observed for various CSO sludges around the country (12). The very high values of BOD's, volatile solids and coliforms indicate that direct disposal of raw sludges may present problems for public health (through possible disease transmission) and development of odor problems. For these reasons, it appears that CSO sludges must be stabilized before land application.

The stabilization method most frequently used is anaerobic digestion. However, there are numerous other acceptable methods, such as aerobic digestion, chemical treatment, heat stabilization or heat drying, and composting, which may be used. A promising method of stabilization for CSO sludges is lime treatment. The use of this method would allow for the stabilization of the CSO sludges either at the site of the CSO treatment facility or at the land disposal site. If dewatering of the CSO sludge is employed in order to reduce transportation and handling costs, lime stabilization can be accomplished prior to dewatering.

A procedure for the lime stabilization of municipal sludges has been developed and operated successfully on a pilot scale (35). Significant reductions in pathogenic bacteria and obnoxious odors resulted from lime treatment. Growth studies indicated that disposal of lime stabilized sludge on cropland produced no detrimental effects.

For high rate application either by entrenchment or sanitary landfill, it has been reported that the sludges should first be limed and dewatered (63). The pH of the sludge at the time of dewatering should exceed 11.5 to reduce pathogen survival and potential nuisance conditions.

Because of the success of stabilization of municipal sludges by lime treatment and the ability to achieve the stabilization at the site of the CSO treatment facility instead of transporting the sludge to a central stabilization facility and also, the ability to treat intermittent flows; lime stabilization should be considered as a feasible preapplication treatment process for a land application system.

Transportation of the Sludge

The solids characteristics of the sludge will be a primary factor influencing the type of transportation selected. If the sludge has a solids content less than 8%, it may be transported by pipelines, tank trucks or tank wagons. When the sludge is dewatered to a solids content of 15% or higher, it must be transported by either dump trucks or manure spreaders. Selection of the desired transportation mode will usually depend on production rate, distance to application site, and planned lifetime of the site.

Many large cities may optimize sludge handling and disposal costs by pumping their liquid sludges relatively long distances through pipelines. However, pipelines are probably uneconomical for small communities due to economics of scale. In addition, convenience and accessability of satellite CSO treatment sites, may make pumping very difficult to implement. As has been previously discussed, the combined sewer areas of most cities are centrally located thus creating two problems: 1) construction in heavily built up areas; and 2) vast pumping distances to avoid urban-suburban areas. These considerations along with other factors such as intermittent peak quantities of sludge to be handled and settling of grit in pipelines would probably make transportation of CSO sludges by pipeline impractical and uneconomical.

The land disposal of liquid CSO sludge can become very expensive if truck hauling is employed over long distances. The costs will be extensively dependent on the hauling distance (which can be great from the CSO treatment sites to the disposal site), the size of the truck, and the quantity of solids being hauled. However, tank trucks provide considerable flexibility with regard to site selection and hauling schedule and have the additional advantage that liquid sludge can be applied directly from the truck. These considerations seem to indicate that tank truck transportation of CSO sludges may be a viable approach.

Thickening and dewatering of the sludge could significantly reduce the operating cost of transporting CSO sludges to a land disposal site. For example, a sludge volume requiring disposal can be reduced fifteenfold if a sludge of one percent solids is thickened and dewatered to 15 percent solids. This in turn, would significantly reduce the city's annual sludge transportation costs.

From the discussion of the transportation aspects of land disposal of CSO sludges, it appears that truck transportation of either liquid or dewatered sludge is the most desirable alternative in CSO areas with significant volumes of sludge to be handled. Truck transportation of dewatered sludges might prove to be the more desirable alternative because it represents a significant reduction in operational costs from trucking the liquid sludges. However, a detailed economic analysis should be required for each individual case to determine if these savings would cover the added costs of thickening-dewatering facilities.

Storage Requirements

Since CSO events are intermittent and thus sludge volumes will not be a continuous flow, storage facilities will be required to maintain a constant application program. Storage will also be required if land disposal is prohibited due to inclement weather, frozen soil and snow cover as well as the possibility of equipment breakdown. As was previously discussed for land application of raw CSO, the average number of nonapplication days for which storage would normally be required in colder climates is about 100 days. Dewatering the sludge would significantly reduce the volumes required for storage even though the solid weights remain the same. For example, if dewatering to 15% solids is used, the volume to be stored is reduced to 1/15 of the original liquid volume. For a dewatered sludge, temporary storage pits have been used into which the sludge is dumped and from which front-end loaders obtained the sludge for application. The pits can then be closed as they become impassable and/or too far from the application area (63).

Liquid sludges are usually stored in tanks or lagoons located at the disposal site. If liquid sludge is stored, settling of the sludge solids will occur in the basin. Therefore, provisions should be made for resuspending these solids before the sludge is applied to the land. The storage facility could also become a source of odor problems and a breeding ground for mosquitoes and other insects, therefore precautions will have to be taken to prevent these problems from occurring. These precautions could be stabilization with lime before storage and a possible insect control program.

A dewatered sludge storage area would not be as troublesome as a storage basin for liquid sludge. However, the dewatered sludge could become a source of odor problems and then some remedial action would be required.

Climatological Effects

The general climate of the area will have some effects on the operation of the disposal site, although the effects will not be as pronounced as that for raw CSO.

The main climatological concern will be the restrictions that inclement weather will impose on the application operation. For the disposal of liquid CSO sludges, rainfall periods will prevent application to the land and therefore, lagoons are usually designed for the site so that they can be used for storage until the weather permits application. During winter weather, the application of both liquid and dewatered sludge may be prohibited because of frozen ground. Any CSO sludges generated during this period must be stored until application is allowed. On the average, the operation of facilities in the Great Lakes region will have to be shut down for about 3 1/2 months.

If the liquid sludge is to be applied by a truck, all-weather roads that would allow for discharge to either side of the road should be constructed at the site. This would help to offset wet periods and compaction problems. For inclement weather operation, flexibility could be established by use of fixed piping or movable irrigation equipment (64). For a dewatered sludge disposal operation, all-weather roads should be provided so that disposal can be utilized during periods of rainfall and wet grounds.

Pollutional Loading Constraints

In applying CSO sludges to the land, the control of loading rates will be based mainly on concerns for the migration of pollutants to the groundwater and the accumulation of heavy metals in the soil and vegetation. As was illustrated using raw CSO, some of the pollutants that may lead to restrictions on the loading rates of sludges to the land will be investigated using similar constraints as that presented earlier. The following CSO values, based on average characteristics, have been assigned for use in this section.

Raw CSO Volume: 1382×10^6 ℓ/yr (365×10^6 gal./yr)
Volume of Sludge as Percent of Volume Treated: 2.8%
Yearly CSO Sludge Volume: 38.6×10^6 ℓ(10.2×10^6 gal.)
CSO Sludge Concentration: 1 percent solids
Yearly CSO Sludge Solids Volume: 386 metric tons (425 tons)-dry weight basis*
Pollutional Characteristics:

SS	10,000	mg/l	
BOD	100	mg/gm	SS
N	12.5	mg/gm	SS
P	10	mg/gm	SS
Zn	1000	mg/kg	
Cu	400	mg/kg	
Ni	200	mg/kg	

Yearly CSO Sludge Volume after Thickening to 4% Solids: 9.8×10^6 ℓ(2.6×10^6 gal.)
Yearly CSO Sludge Volume after Dewatering to 15% Solids: 2.6×10^6 ℓ (0.7×10^6 gal.)

Toxic Elements - Restrictions have been placed on the practice of land disposal in order to limit the maximum loading of the metals on the land (16). Wisconsin has developed an approach which takes into account the combined effect of the metals by using a measurement entitled the zinc equivalent. This was presented and discussed in the previous section. From this approach it is possible for a standard to be developed which would maintain heavy metal concentrations below toxic levels.

Since calculation of the ZE of the CSO sludge material requires knowledge of zinc, nickel and copper concentrations, it was assumed that the concentrations (mg/kg) will be similar to raw CSO. Using the Wisconsin approach, the acceptable total zinc equivalent loading would approximate 21 metric tons/ha/yr (9.4 tons solids/ac/yr) for soils having cation exchange capacities of 15 meq/100 gm and 20 year designed life. Thus, the area requirements

*All metric tons throughout this section are expressed on a dry weight basis for safe control of toxic metals would be about 4.7×10^{-2} ha/metric ton/yr (10.6×10^{-2} ac/ton/yr).

In addition to the metal equivalents' limitations, cadmium additions may become a serious limiting parameter because of its toxicity effects to both humans and plants. Cadmium loadings must be limited to a maximum of 2.2 kg/ha/yr (2 lb/ac/yr) and the total site lifetime maximum of 22 kg/ha (20 lb/ac) (65). To determine loading constraints, a cadmium value of 40 mg/kg was assumed. The calculation of loading rates indicate that cadmium loadings limit annual application to 56 metric tons/ha (25 tons/ac) and overall cadmium loading to 560 metric tons/ha (250 tons/ac), assuming a 20 year site life. Therefore, the area requirements necessary for safe applications of cadmium would be about 1.8×10^{-2} ha/metric ton/yr (4.0×10^{-2} ac/ton/yr). It is apparent that from the differences in land area requirements the metal equivalents are the limiting loading constraints in the application of toxic materials to the land.

Nitrogen and Phosphorus Control - In determining the allowable loading of nitrogen to the land, the objective shall be to match as closely as possible the quantity of nitrogen removed from the soil by the harvesting of the crop. The allowable loading rate will thus be determined by the nutrient content of the sludge and the nutrient uptake capabilities of the particular crop under consideration. The rate of application for CSO sludges can be calculated using the same equation as that used for the application of raw CSO. Additional assumptions that had to be made included: 1) crop nitrogen removal rate for corn is 201 kgN/ha-yr (180 lb N/ac-yr) and 2) the nitrogen concentration in CSO sludges is 12.5 mg TKN/gm SS or 125 mg/l.

Using these assumptions, the sludge application rate would be approximately 255.4 kg N/ha-yr (228 lb N/ac-yr) thus resulting in a land area requirement of 4.9×10^{-2} ha/metric ton sludge/yr (11.1×10^{-2} ac/ton sludge/yr). If grass is grown instead of corn, the land area requirements could be reduced to 3.7×10^{-2} ha/metric ton sludge/yr (8.2×10^{-2} ac/ton sludge/yr).

Besides nitrogen, phosphorus has also been a nutrient of concern. Current restrictions limit phosphorus annual loading rates within the 68 to 136 kg P/ha-yr (150-300 lb P/ac-yr) range. On this basis, the total land area required for safe application of phosphorus should not exceed 4.0×10^{-2} ha/metric ton sludge/yr (8.9×10^{-2} ac/ton sludge/yr) for CSO sludges containing P concentrations of 10 mg P/gm SS.

Organic Application Rates - Although the rate of organic carbon oxidation in soils is known to be high, limitations for waste additions are not adequately established. A few regulations have been proposed to limit BOD_5 application rates to around 672.6 kg/ha-day (600 lbs/ac-day). However, Jewell (66) recently reported that a soil system could degrade organics at a rate exceeding 4480 kg/ha-day (4000 lb/ac-day). If this latter limitation is used, the safe application areas for CSO organics would be 2.3×10^{-2} ha/metric ton sludge/yr (5.2×10^{-2} ac/ton sludge/yr).

Hydraulic Loading - Since the permeability of much of the area in the northern states exceeds 5 cm per hr (2 in./hr), it can be inferred that the transmission of water from the sludge would be a minimal problem. However, the application of the more dilute sludges (i.e. 1% solids) may be restricted to several application periods per year to prevent surface flooding and runoff.

Land Area Requirements - The actual land area required for the disposal of the CSO sludges, either liquid or dewatered, will be dependent on the allowable application rates which, in turn, will be dependent on the soil type, the nutrient and heavy metals content of the particular sludge, and the nutrient uptake characteristics of any vegetation crops on the site.

For field area requirements, a summary of the application rates estimated to be acceptable and the resulting land requirements are shown in Table 40. Similar to raw CSO, the limiting pollutant loading factor is the nitrogen content of the sludges. Nitrogen is most often the limiting factor for application of municipal sludges. If nitrogen limitations determine the required land area, it can be seen that the application rates of the other pollutants are one-third to two-thirds that which is assumed to be an environmentally safe rate of application. Recommendation of the use of a 5.3×10^{-2} ha/metric ton sludge/yr (11.8×10^{-2} ac/ton sludge/yr) land area requirement should provide a safety factor large enough to account for any unpredictable events. This application is equivalent to adding a CSO sludge (4% solids) once at a depth of 4.8 cm (1.9 in.); or an application rate equal to 19.0 metric tons/ha/yr (8.5 tons/ac/yr).

These land requirements are for the actual application only and, as shown in the discussion of land disposal of the raw CSO, additional land may be required for roads, buffer zones, possible storage and pretreatment facilities, etc. In studies of land application of municipal wastewater plant effluents, it has been found that only 70 percent of the total site area is available for actual application (67).

Employing the above application rate of 19.0 metric tons/ha/yr (8.5 tons/ac/yr), and if the nationwide annual generation of CSO solids totals 1.57×10^6 metric tons (1.73×10^6 tons), field area requirements for CSO sludges, either liquid or dewatered, would approximate 82×10^3 ha (203×10^3 acres) of land. Assuming that, on the average, the land required for actual disposal is 70 percent of the entire disposal site, the nationwide disposal of CSO sludges would require a total land area of 118×10^3 ha (290×10^3 acres).

Application Techniques

The application technique that is employed at a specific land disposal site will be dependent to a large extent on the characteristics of the site, physical properties and quantity of sludge, and the objectives of the land disposal program. The techniques presented here are those that have been reported in the literature for municipal treatment plant sludges.

Systems are available for surface and subsurface application of liquid sludges. Surface application of liquid sludge is generally accomplished by ridge and furrow irrigation or by tank truck land spreading. The most common technique is direct application to the land by spraying from tank wagons. Most communities employing this technique use city-owned tank trucks with capacities ranging from 3.8 to 18.9 cu m (1,000 to 5,000 gal.) and equipped with various spreading devices operated by gravity or pumping (64). The tank truck has the advantage that it can also be used for sludge transport. Liquid manure spreaders, pulled by farm tractors, have been found to be very effective and accurate in the application of the sludge to the soil. It may be desirable to incorporate the sludge into the soil as soon as possible following application in order to prevent possible odor and runoff problems.

TABLE 40. SUMMARY OF RECOMMENDED DRY SLUDGE SOLIDS APPLICATION RATES FOR VARIOUS CSO SLUDGE POLLUTANTS AND THE RELATED LAND AREA REQUIREMENT

	Acceptable application rate		Land area requirement	
Pollutant	kg/hr/yr	(lb/ac/yr)	10^{-2} ha/metric ton/yr	(10^{-2} ac/ton/yr)
Toxic	21.0[a]	(9.4)[a]	4.7	(10.6)
Nitrogen	255.6	(288)	4.9	(11.1)
Phosphorus	252	(225)	4.0	(8.9)
Organics	4,484[b]	(4000)[b]	2.3	(5.2)

[a] Expressed as metric tons/ha/yr (ton/ac/yr) - dry weight basis

[b] Expressed as kg/ha/day (lb/ac/day)

Flooding and ridge and furrow irrigation methods have also been used as sludge application techniques. Ridge and furrow has the advantage that it is suitable for row crops during the growing season.

Soil incorporation of liquid sludge can be accomplished in a number of ways. The most common methods are plow-furrow cover and subsurface injection. The plow-furrow-cover method involves the spreading of sludge in a narrow swath from a wagon and immediately covering the waste using a plow. Subsurface injection involves the discharging of liquid sludge into subsurface channels caused by chisel-like plows.

Another disposal technique has been used at non-agricultural land sites. Disposal by small treatment plants may incorporate digging of shallow trenches, filling them with liquid sludge and covering the sludge with soil to prevent nuisance conditions (69). The literature shows that, with the use of ridge and furrow irrigation, trench disposal, and flooding techniques on non-agricultural land, it is possible to use greatly increased loading rates. However, groundwater and other public health consideration may place significant constraints on these loading rates.

When dewatered sludge is applied to the land, the usual method of application is to spread the sludge on the land and then disc it into the soil using earth moving equipment and farm machinery. The one disadvantage of this method is that it may be difficult to break up the sludge cake in such a manner that it can be easily spread.

Entrenchment is another application method that has been employed. Entrenchment has been found to be a feasible method for simultaneously disposing of sewage sludges and improving marginal agricultural land, particularly for dewatered (20% solids) raw, lime treated sludge (63).

In devising an application system for land disposal of CSO sludges, minimizing costs and maximizing the application season should be the major considerations. The preceeding discussion shows that there is a very wide range of application techniques that have been used with varying application systems. It appears that many considerations may dictate the possible application technique at the site, however, the most economical application technique should be selected.

Growth Of Crops On The Site

For the disposal of CSO sludges on agricultural land, the growth of crops or vegetation on the disposal site can be a very important aspect of the site operation. The basic reason for cultivating crops or a vegetative cover is to achieve nitrogen uptake so that the nitrogen is removed from the soil and ultimately removed from the site when the crops or vegetation are harvested (64).

It is generally agreed that alfalfa is a most desirable crop, particularly if sufficient nitrogen is available in the sludge to eliminate nodule formation on the root structure (64). This ensures that the maximum uptake of nitrogen occurs and that the movement of nitrates into either ground or surface water will be minimized. By cutting alfalfa three or four times during the growing seasons increased quantities of nutrients may be removed. In addition, each cutting allows for additional sludge application. This would be advantageous for the more dilute sludges requiring several application periods.

Corn is perhaps the next best and most widely used cover crop, having the advantages of high nitrogen uptake and good saleability. It has limited flexibility for sludge application during the growing season unless the ridge and furrow method of liquid sludge application can be used.

The other general purpose group of crops is the forage grasses. The greatest advantage of these crops, in addition to nitrogen uptake, is their accessibility in inclement weather, during early spring planting, in late fall before the soil cools down, and during the active growing season when other crops restrict tank truck operation (64).

Monitoring Program

The application of sludge to land disposal sites must be managed to minimize the risks of nitrogen and pathogen contamination of surface and groundwaters; to minimize the risks of soil degradation by metal overloading and of toxic metal uptake by crops; to minimize the risks of pathogen transmission by insects and animals; and to minimize offensive odors. Thus, the monitoring program employed at the disposal site will be extremely important. A comprehensive monitoring program, as that suggested earlier, will be essential to ensure that proper renovation of the CSO is proceeding without degradation of environmental quality.

Application rates should be subject to good record keeping and monitoring because overloading of a particular soil can be a major reason for failure of a land site. Caution should be used in dealing with acid soils because of the possible release of heavy metals. Here the general rule is to maintain a pH above 6.5 to control heavy metal solubility (64).

Summary

In discussing the logistics of treatment and disposal of CSO sludges, it is apparent that land application in general may be extremely feasible, both practically and economically. Therefore, the municipality or sanitary district should regard land application as a viable alternative. However, its implementation should be based upon this alternative being the least-cost acceptable means of sludge handling and disposal.

Three management options are available: 1) land spreading a dilute sludge (1% solids); 2) land spreading a thickened sludge (4-8% solids); and 3) land spreading a dewatered sludge (>12% solids). It should be noted that land area requirements are the same for all three options, however, the solids handling and disposal costs will differ greatly. The high costs associated with transporting, storage and intermittent application of dilute sludges will probably cause option one to be least cost-effective. In most cases, options two and three will be economically feasible. The difference will depend on transporting and storing costs versus additional dewatering costs.

Land application of CSO sludges has one major limitation which must be considered when evaluating the cost-effectiveness of this alternative to that of another management technique. Before sludge can be disposed, it must first be treated (stabilized) to reduce adverse impact on receiving land. From some stabilization processes, this can be a very costly expenditure. The most promising and possibly the most cost-effective method of stabilization of CSO sludges may be lime treatment.

SECTION VIII

ECONOMIC IMPACT OF HANDLING CSO TREATMENT RESIDUALS

INTRODUCTION

The economic impact of handling CSO residuals is difficult to estimate on a generalized basis. This section presents basic economic data to approximate the costs associated with handling generated volumes of CSO sludges using various CSO treatment systems. It is emphasized at this point that the costs presented herein are guidelines and are included only as a first approximation of the actual costs involved. If a detailed economic evaluation is necessary or desired, the individual site must be evaluated separately with respect to locale, rainfall patterns, type and location of treatment system, etc. Then the equipment costs should be established by estimates of manufacturers, not by generalized cost curves. However, the information presented will allow an approximation of the ranges of costs for handling CSO treatment residuals throughout the country and is valuable when properly applied.

BASES OF COST ESTIMATES

In providing cost estimates, it was desirable to utilize similar bases for all of the treatment trains evaluated. This was done, as much as possible, by utilizing published cost curves or other data and then adjusting them to reflect June, 1976 prices. Whenever a similar unit process was applied in different schemes, the same cost estimating structure was used.

When satellite treatment systems were evaluated, the same four systems were considered for each site. These included the following:

1. Lime Stabilization → Storage → Gravity Thickening → Vacuum Filtration → Landfill
2. Lime Stabilization → Storage → Gravity Thickening → Vacuum Filtration → Land Application
3. Lime Stabilization → Storage → Gravity Thickening → Land Application
4. Lime Stabilization → Storage → Land Application

An average of the annual CSO sludge volume was used to establish system design flow rates and the following assumptions were made to size equipment:

1. Storage - store 48 hours of CSO sludge.
2. Lime Stabilization - treat within 24 hours.
3. Gravity Thickening - treat within 48 hours.
4. Vacuum Filtration - treat within 48 hours.

It was assumed for all cities, that half of the rainfall results in combined sewer overflow and of this volume, a fixed percentage is CSO sludge, depending upon the CSO treatment system used. Also it was assumed that addition of lime for stabilization increased the solids to be handled by 15%. (35). Figures 13 - 17 were used to estimate capital costs for pumping, gravity thickening, lime stabilization, vacuum filtration and landfill (43). Storage tank costs were estimated using unit costs per volume as listed below (69).

Tanks:

m^3	Gallons	\$ Installed
936	(250,000)	98,000
1872	(500,000)	150,000
3744	(1,000,000)	230,000
7488	(2,000,000)	355,000
14976	(4,000,000)	560,000
22464	(6,000,000)	760,000

Operation and maintenance costs were estimated from several sources. Figures 18 - 23 included manpower and utilities costs for pumping, gravity thickening and vacuum filtration. These costs were adjusted to dollars using a daily rate of \$32 per man-day and utilities cost of \$0.001/KWhr. Lime stabilization operating and maintenance costs were estimated based on published data regarding lime stabilization (35):

Sludges from physical treatment = \$9-10/metric ton (\$8-9/ton)
Sludges from physical/chemical treatment = \$14-19/metric ton (\$13-17/ton)
Sluges from biological treatment = \$13-17/metric ton (\$12-15/ton)

Landfill operation and maintenance costs were based on these presented in Figure 24 and then adjusted to June, 1976 values (70).

Transportation costs utilized depended upon the type of sludge, percent solids, and distance to landfill or land application site. The solids concentrations utilized were: Lime Stabilized only - 1%
Gravity Thickened - 5%
Vacuum Filtered - 20%

Distances used were dependent upon the size of the CSO area in the city. The approximate distances were estimated from the following:

CSO Area	Distance
0-202ha (0-500 acres)	32.2km (20mi)
203-2307ha (501-5700 acres)	32.2km (20mi)
2308-10118ha (5701-25000 acres)	64.4km (40mi)
10119-24282ha (25001-60000 acres)	64.4km (40mi)

Once these assumptions were established, then annual transportation costs were estimated using Figures 25 and 26. Land application cost estimates consisted of several individual components including storage requirements, distribution costs, land requirements and costs and land preparation costs. It was assumed that liquid sludge would be applied periodically throughout the growing

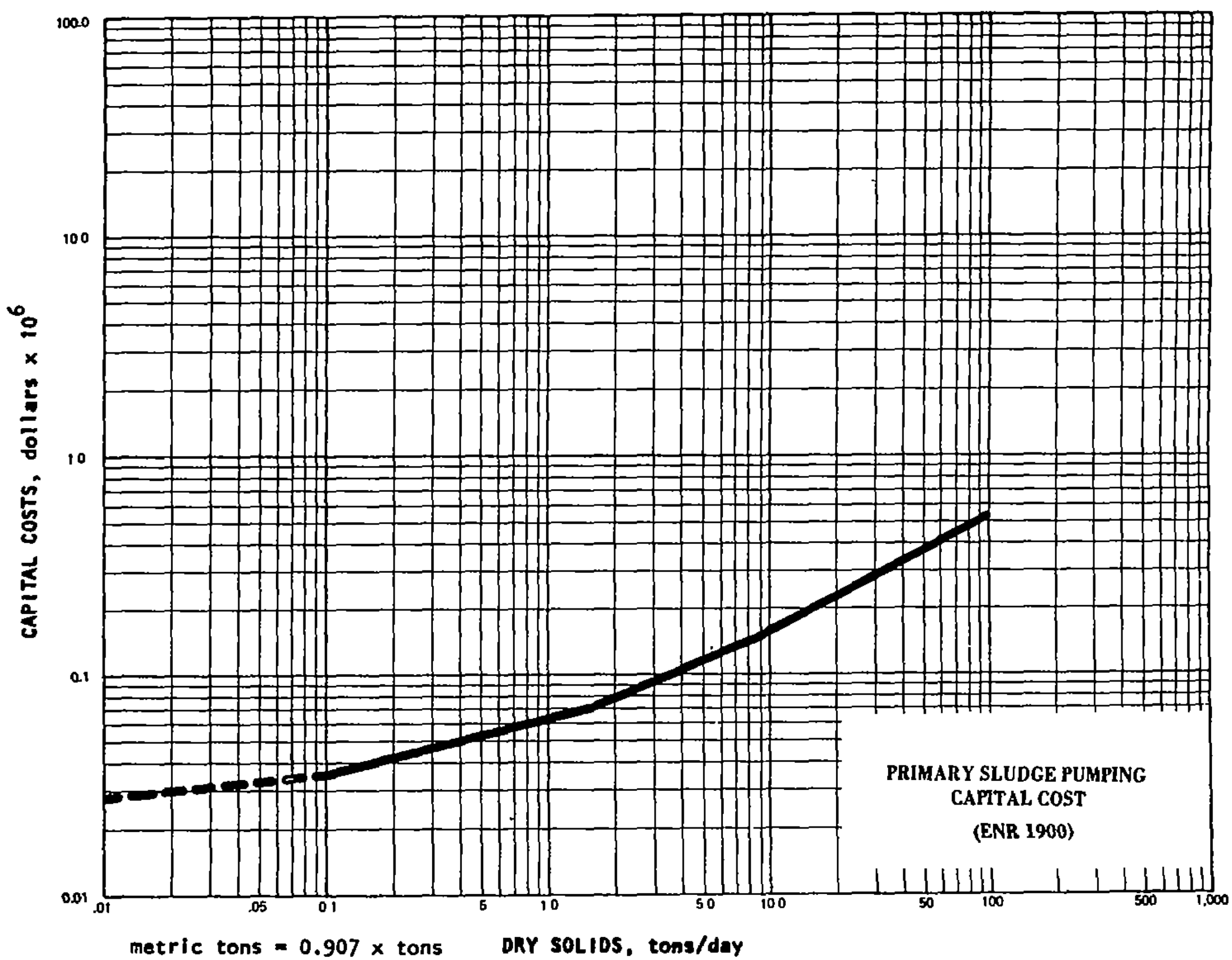


Figure 13. Capital cost estimate basis-primary sludge pumping (43).

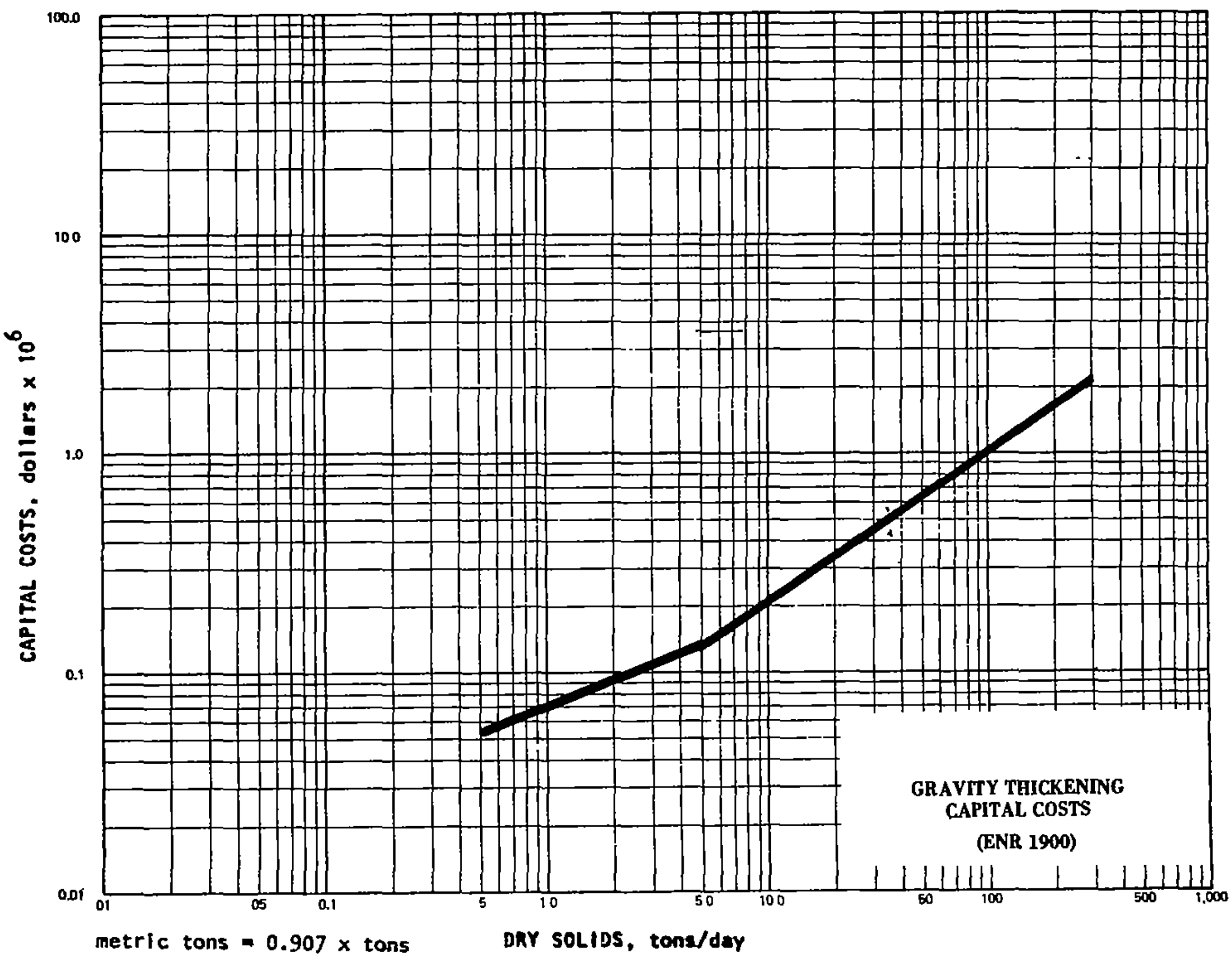
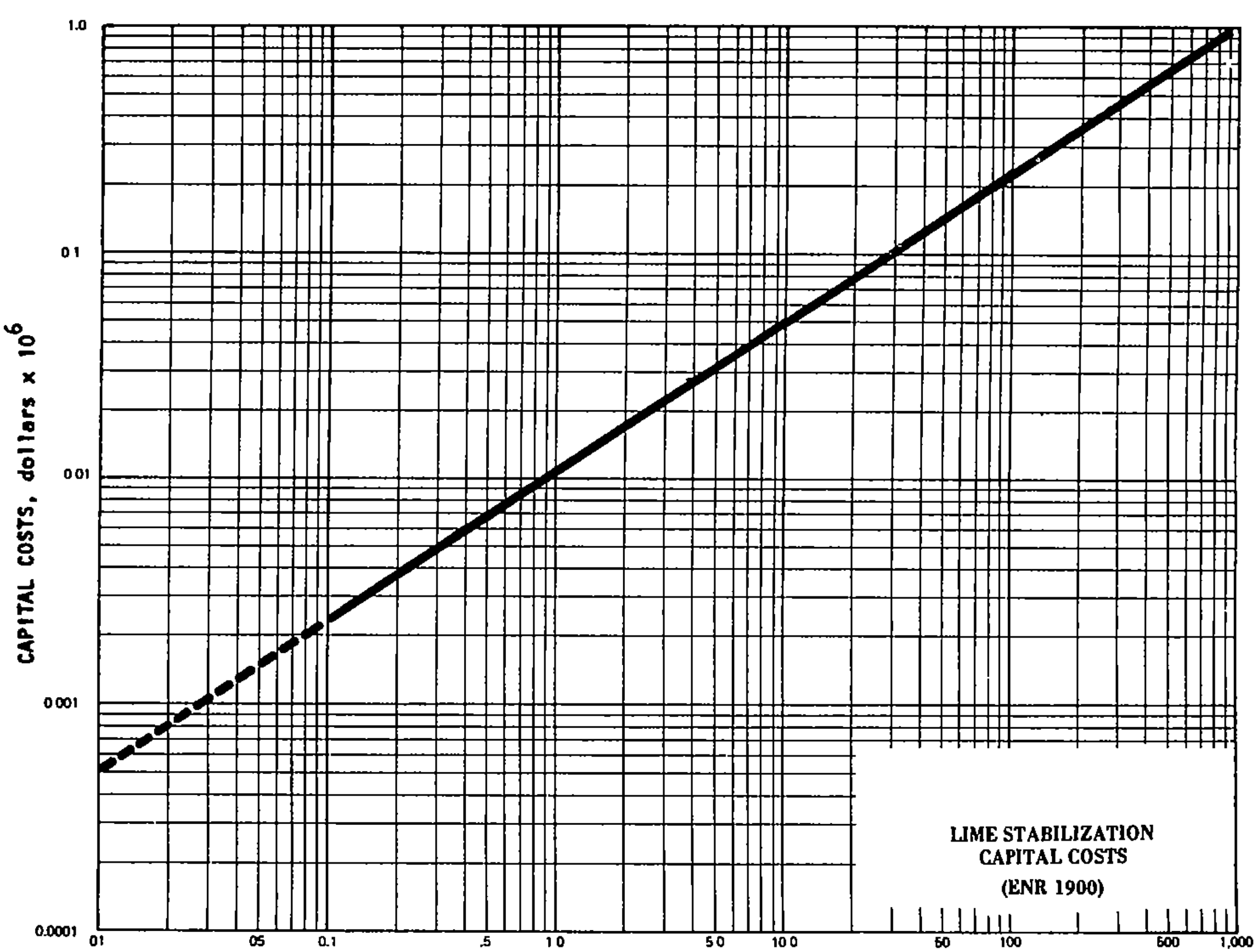


Figure 14. Capital cost estimate basis~gravity thickening (43).



metric tons = 0.907 x tons DRY SOLIDS, tons/day

Figure 15. Capital cost estimate basis-lime stabilization (43).

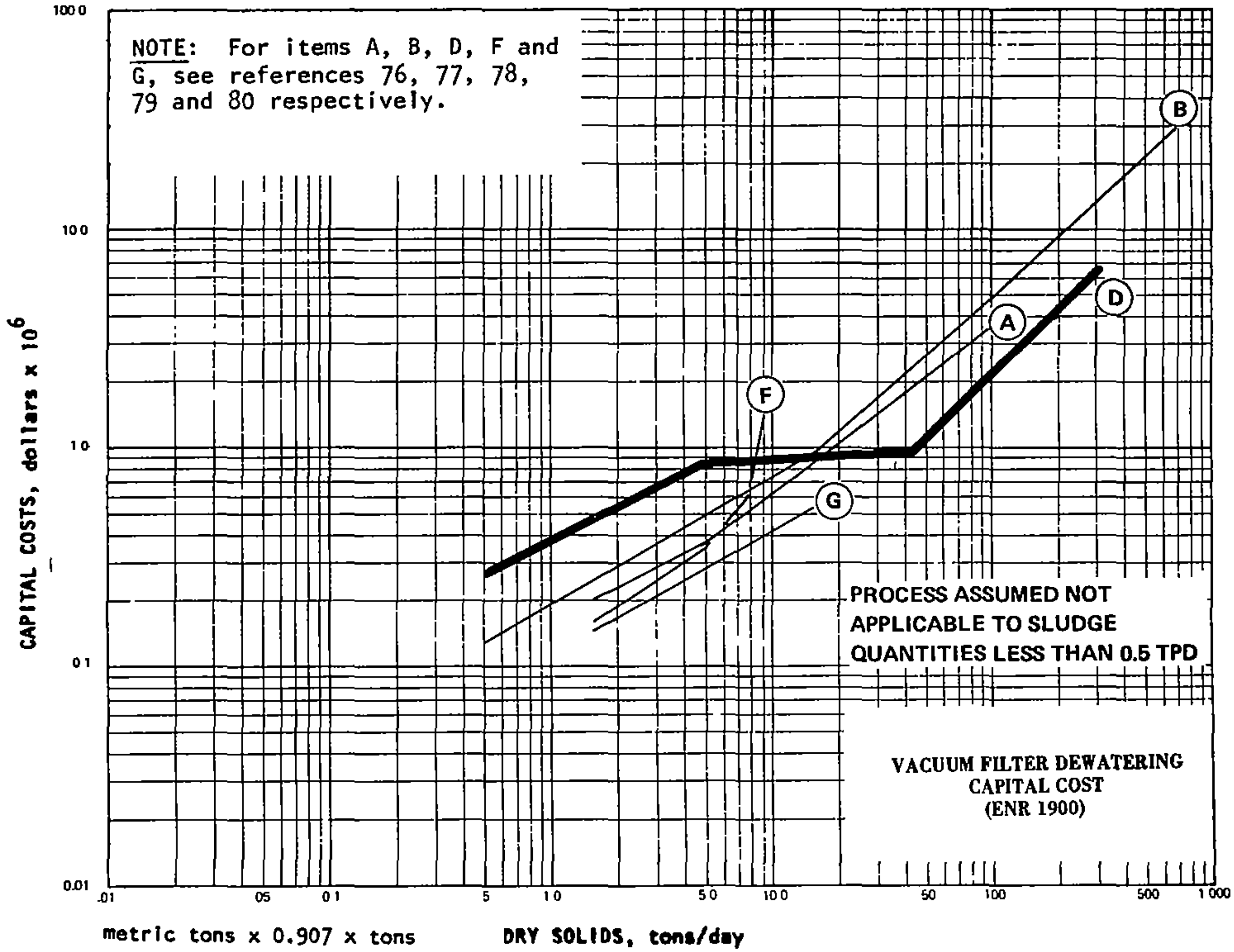


Figure 16. Capital cost estimate basis-vacuum filter dewatering (43).

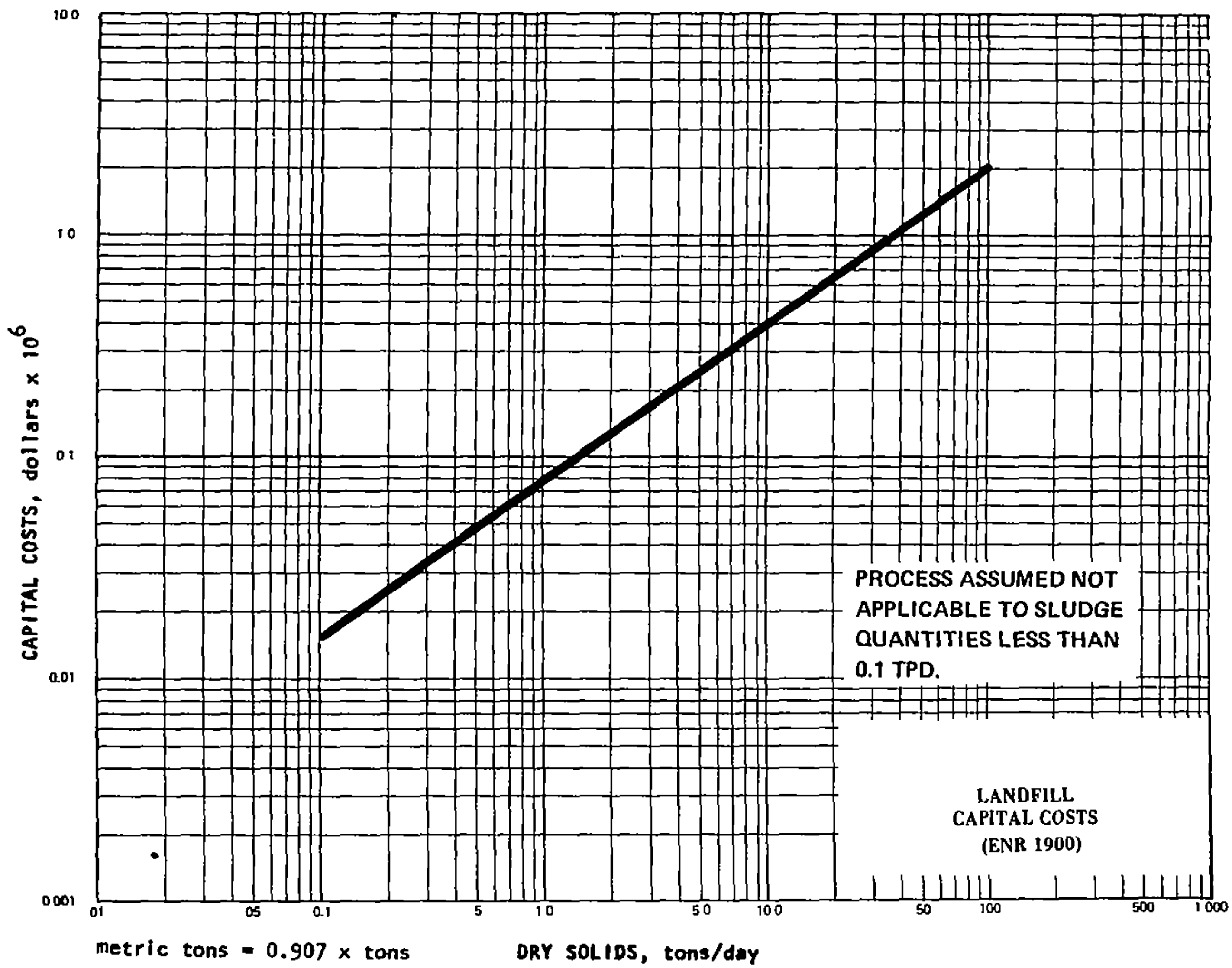


Figure 17. Capital cost estimate basis-landfill (43).

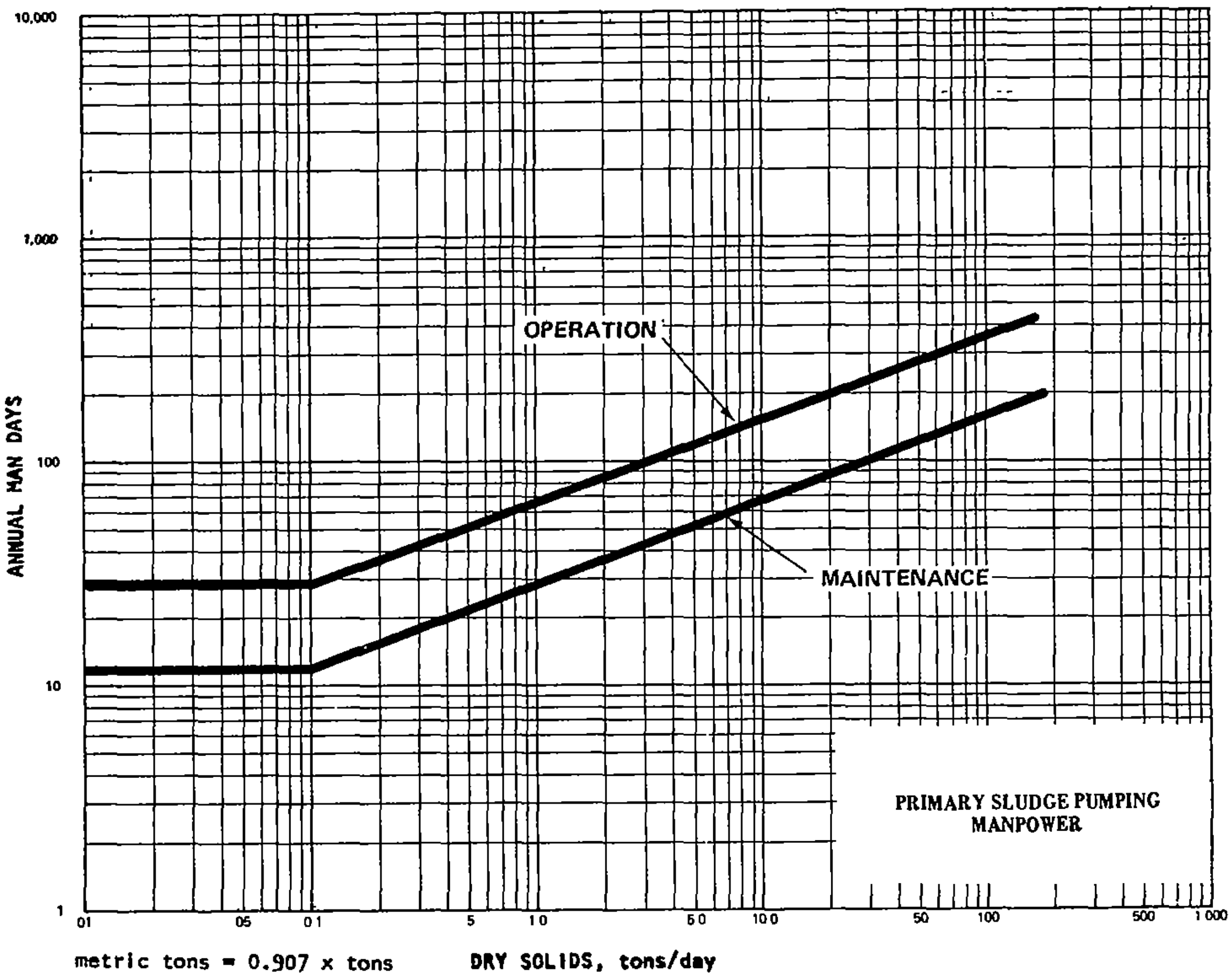


Figure 18. Manpower cost estimate basis-primary sludge pumping (43).

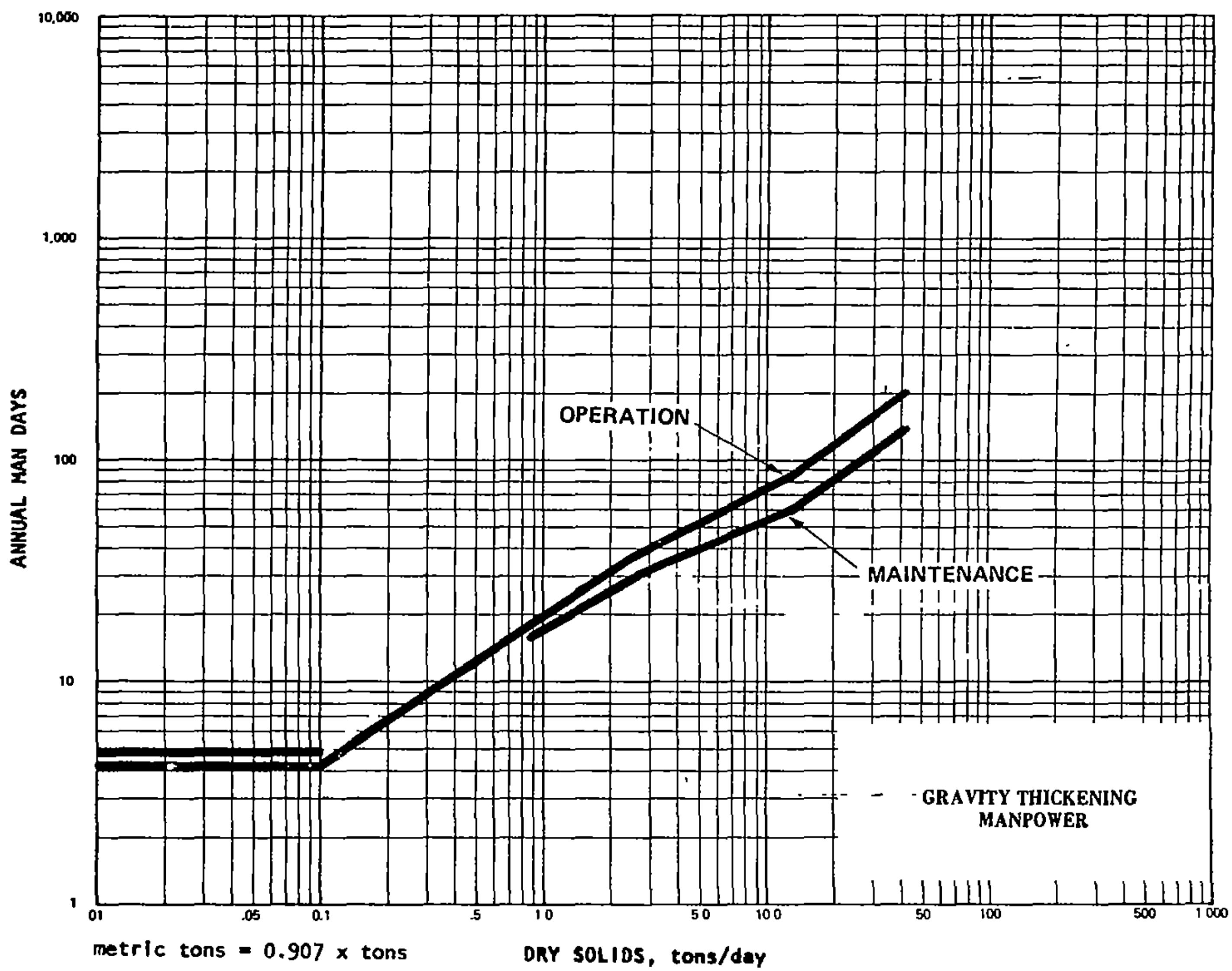


Figure 19. Manpower cost estimate basis-gravity thickening (43).

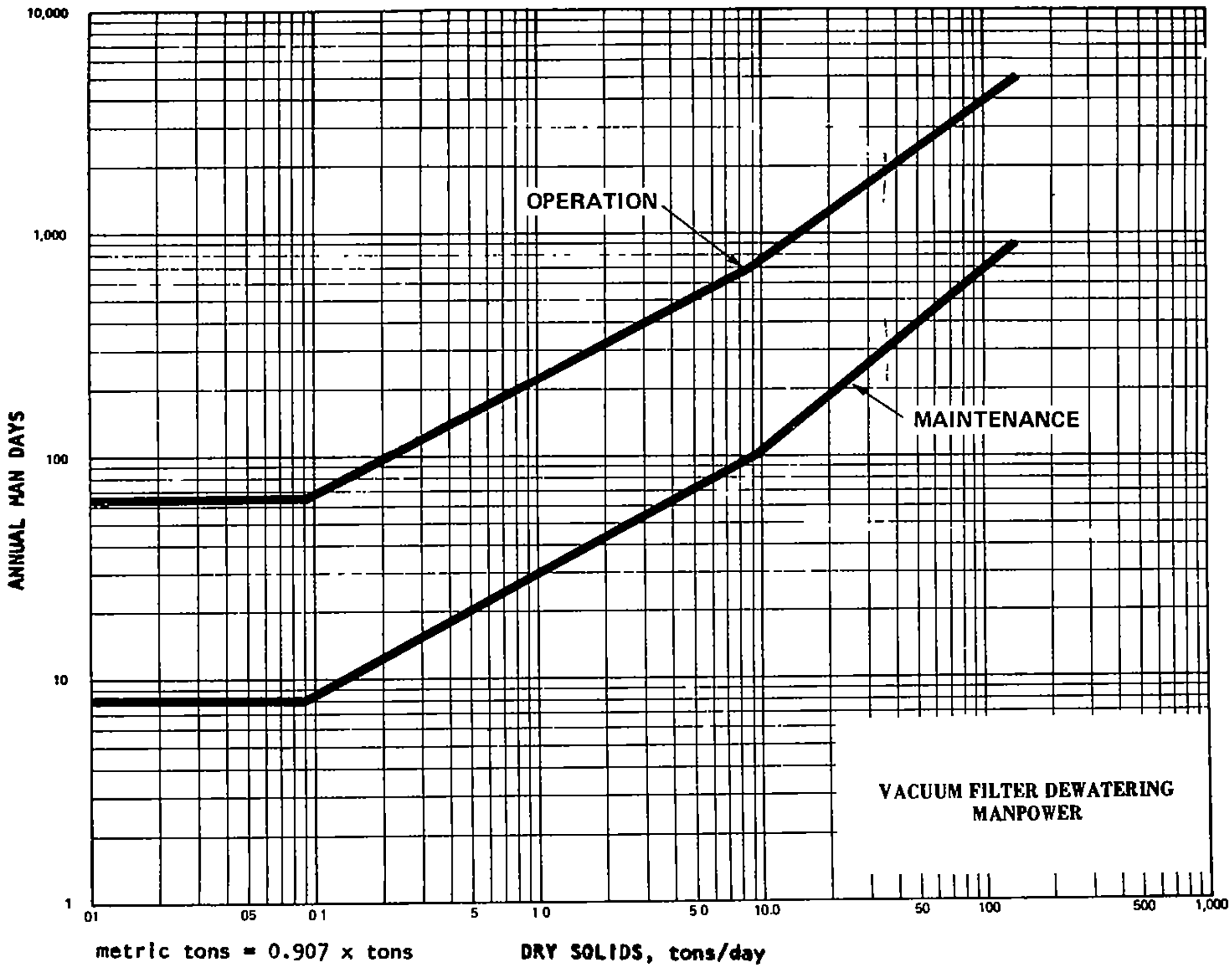
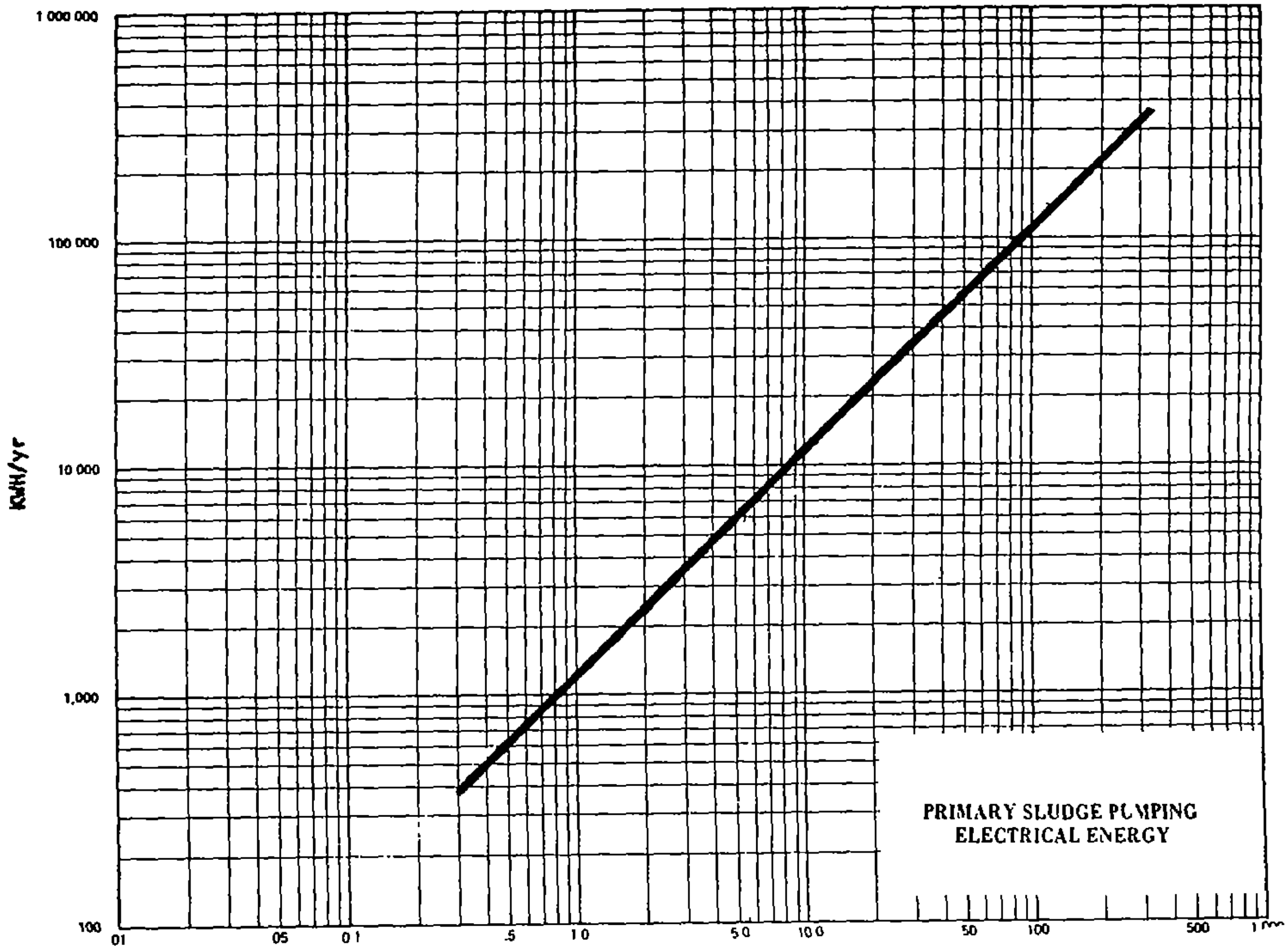


Figure 20. Manpower cost estimate basis-vacuum filter dewatering (43).



metric tons = 0.907 x tons   **DRY SOLIDS, tons/day**

Figure 21. Electrical energy cost estimate basis-primary sludge pumping (43).

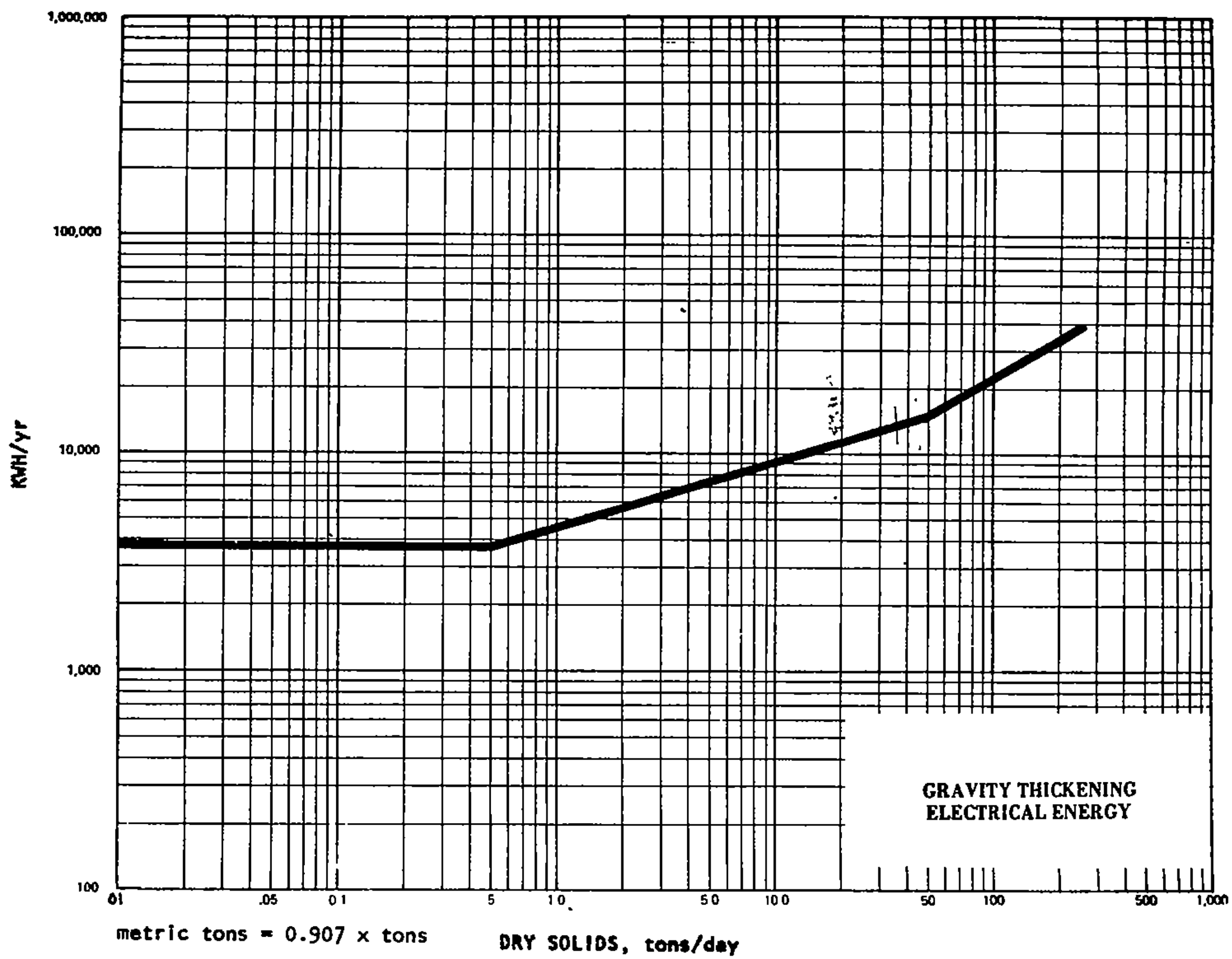


Figure 22. Electrical energy cost estimate basis-gravity thickening (43).

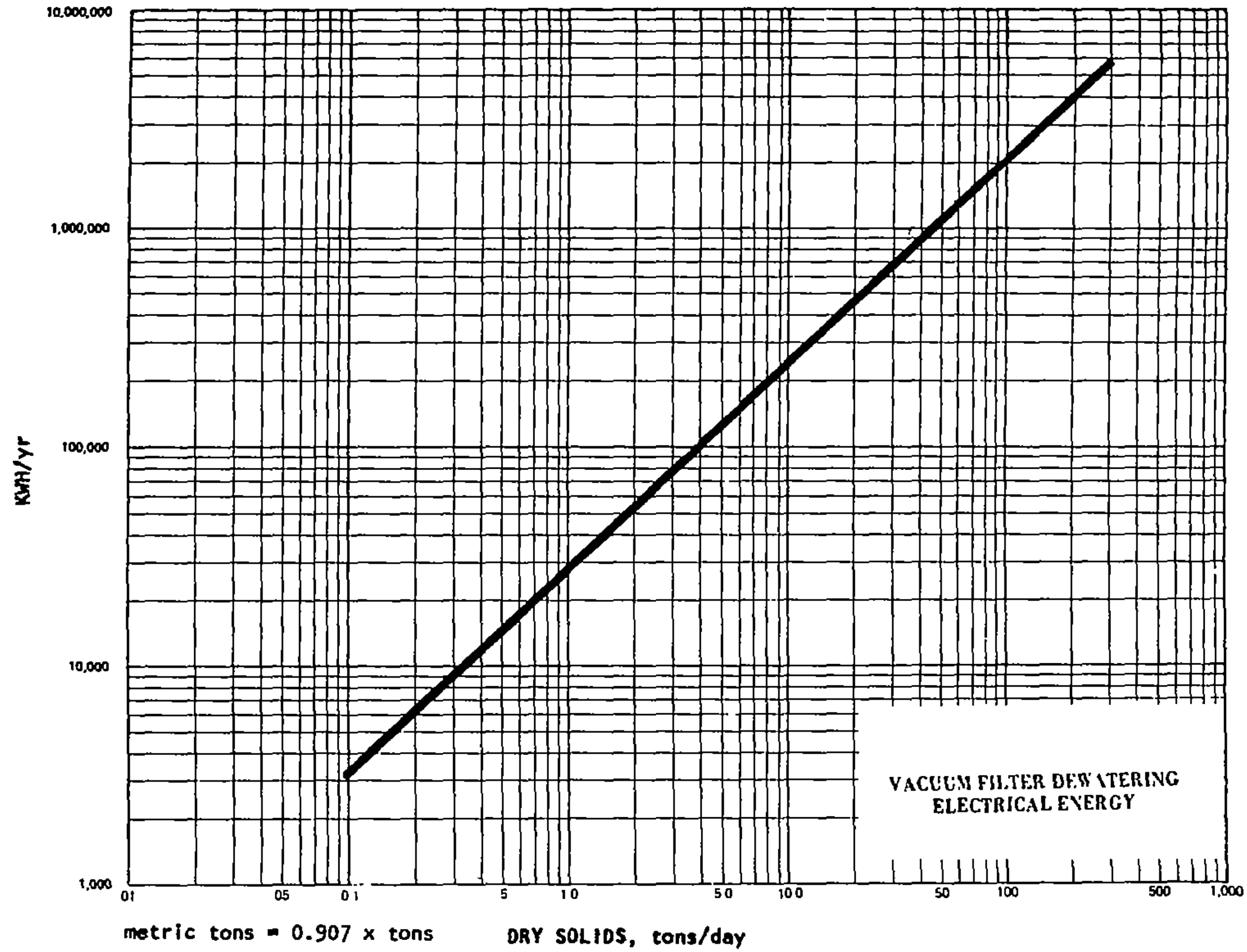
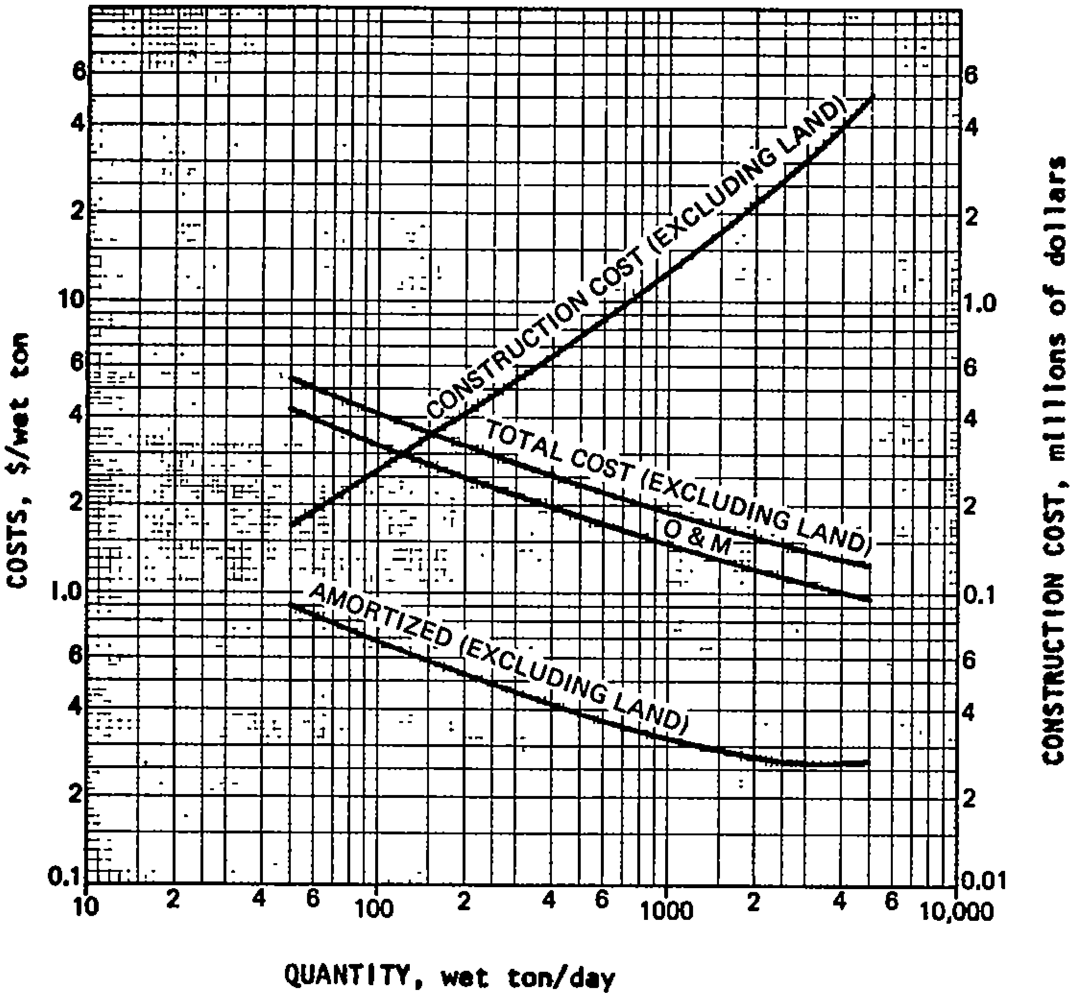


Figure 23. Electrical energy cost estimate basis - vacuum filter dewatering (43).



NOTES:

1. Minneapolis. Mar., 1972. ENR Construction Cost Index of 1827.
2. Amortization of 7% for 20 years.
3. Labor rate of $6.25 per hour.
4. Quantity assumes 6-day work week.
5. Wet sludge must be considered for cost per ton.
6. Source: U. S. P. H. S. and Stanley Consultants.

NOTE: $/ton ÷ .907 = $/metric ton
ton/day X .907 = metric ton/day

Figure 24. Capital and O/M costs for sanitary landfills (22).